Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

1119

Issued December 19, 1908.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 203.

A. C. TRUE, Director.

DISTRIBUTION OF WATER IN THE SOIL IN FURROW IRRIGATION.

BY

R. H. LOUGHRIDGE, PH. D.,
OF THE UNIVERSITY OF CALIFORNIA,

UNDER THE DIRECTION OF

SAMUEL FORTIER,
Chief of Irrigation Investigations.

LIBRAR
RECEIVED
★ DEC 21 1908
U. S. Dep't of Agriculture.
ANSWERED..............

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

LIST OF PUBLICATIONS OF THE OFFICE OF EXPERIMENT STATIONS ON IRRIGATION.

NOTE.—Publications marked with an asterisk (*) are not available for distribution.

*Bul. 36. Notes on Irrigation in Connecticut and New Jersey. By C. S. Phelps and E. B. Voorhees. Pp. 64.
*Bul. 58. Water Rights on the Missouri River and its Tributaries. By Elwood Mead. Pp. 80.
*Bul. 60. Abstract of Laws for Acquiring Titles to Water from the Missouri River and its Tributaries, with the Legal Forms in Use. Compiled by Elwood Mead. Pp. 77.
Bul. 70. Water-right Problems of Bear River. By Clarence T. Johnston and Joseph A. Breckons. Pp. 40.
*Bul. 73. Irrigation in the Rocky Mountain States. By J. C. Ulrich. Pp. 64.
*Bul. 81. The Use of Water in Irrigation in Wyoming. By B. C. Buffum. Pp. 56.
*Bul. 86. The Use of Water in Irrigation. Report of investigations made in 1899, under the supervision of Elwood Mead, Expert in Charge, and C. T. Johnston, assistant. Pp. 253.
*Bul. 87. Irrigation in New Jersey. By Edward B. Voorhees. Pp. 40.
*Bul. 90. Irrigation in Hawaii. By Walter Maxwell. Pp. 48.
Bul. 92. The Reservoir System of the Cache la Poudre Valley. By E. S. Nettleton. Pp. 48.
*Bul. 96. Irrigation Laws of the Northwest Territories of Canada and of Wyoming, with Discussions by J. S. Dennis, Fred Bond, and J. M. Wilson. Pp. 90.
*Bul. 100. Report of Irrigation Investigations in California, under the direction of Elwood Mead, assisted by William E. Smythe, Marsden Manson, J. M. Wilson, Charles D. Marx, Frank Soulé, C. E. Grunsky, Edward M. Boggs, and James D. Schuyler. Pp. 411.
*Bul. 104. Report of Irrigation Investigations for 1900, under the supervision of Elwood Mead, Expert in Charge, and C. T. Johnston, assistant. Pp. 334. (Separates only.)
*Bul. 105. Irrigation in the United States. Testimony of Elwood Mead, Irrigation Expert in Charge, before the United States Industrial Commission, June 11 and 12, 1901. Pp. 47.
Bul. 108. Irrigation Practice Among Fruit Growers on the Pacific Coast. By E. J. Wickson. Pp. 54.
Bul. 113. Irrigation of Rice in the United States. By Frank Bond and George H. Keeney. Pp. 77.
*Bul. 118. Irrigation from Big Thompson River. By John E. Field. Pp. 75.
*Bul. 119. Report of Irrigation Investigations for 1901, under the direction of Elwood Mead, Chief. Pp. 401. (Separates only.)
Bul. 124. Report of Irrigation Investigations in Utah, under the direction of Elwood Mead, Chief, assisted by R. P. Teele, A. P. Stover, A. F. Doremus, J. D. Stannard, Frank Adams, and G. L. Swendsen. Pp. 330.
Bul. 130. Egyptian Irrigation. By Clarence T. Johnston. Pp. 100.
*Bul. 131. Plans of Structures in use on Irrigation Canals in the United States, from drawings exhibited by the Office of Experiment Stations at Paris, in 1900, and at Buffalo, in 1901, prepared under the direction of Elwood Mead, Chief. Pp. 51.
*Bul. 133. Report of Irrigation Investigations for 1902, under the direction of Elwood Mead, Chief. Pp. 266.
Bul. 134. Storage of Water on Cache la Poudre and Big Thompson Rivers. By C. E. Tait. Pp. 100.
Bul. 140. Acquirement of Water Rights in the Arkansas Valley, Colorado. By J. S. Greene. Pp. 83.
Bul. 144. Irrigation in Northern Italy—Part I. By Elwood Mead. Pp. 100.
Bul. 145. Preparing Land for Irrigation and Methods of Applying Water. Prepared under the direction of Elwood Mead, Chief. Pp. 84.
*Bul. 146. Current Wheels: Their Use in Lifting Water for Irrigation. By Albert Eugene Wright. Pp. 38.
Bul. 148. Report on Irrigation Investigations in Humid Sections of the United States in 1903. Pp. 45.
Bul. 157. Water Rights on Interstate Streams. By R. P. Teele and Elwood Mead. Pp 118. (Separates only.)
*Bul. 158. Report on Irrigation and Drainage Investigations, 1904. Under the direction of Elwood Mead, Chief. Pp. 755. (Separates only.)
Bul. 167. Irrigation in the North Atlantic States. By Aug J. Bowie, jr. Pp. 50.
Bul. 168. The State Engineer and His Relation to Irrigation. By R. P. Teele. Pp. 99.
Bul. 172. Irrigation in Montana. By Samuel Fortier, assisted by A. P. Stover and J. S. Baker. Pp. 108.

[Continued on third page of cover.]

1119 Issued December 19, 1908.

U. S. DEPARTMENT OF AGRICULTURE.
OFFICE OF EXPERIMENT STATIONS—BULLETIN 203.
A. C. TRUE, Director.

DISTRIBUTION OF WATER IN THE SOIL IN FURROW IRRIGATION.

BY

R. H. LOUGHRIDGE, Ph. D.,
OF THE UNIVERSITY OF CALIFORNIA,

UNDER THE DIRECTION OF

SAMUEL FORTIER,
Chief of Irrigation Investigations.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

OFFICE OF EXPERIMENT STATIONS.

STAFF.

A. C. True, Director.
E. W. Allen, Assistant Director.

IRRIGATION INVESTIGATIONS.

Samuel Fortier, Chief.
R. P. Teele, Editorial Assistant and Acting Chief in absence of the Chief.

IRRIGATION ENGINEERS AND IRRIGATION MANAGERS.

A. P. Stover, Irrigation Engineer, in charge of work in Oregon.
C. E. Tait, Irrigation Engineer, in charge of work in Imperial Valley and Arizona.
F. W. Roeding, Irrigation Manager, in charge of work in California.
S. O. Jayne, Irrigation Manager, in charge of work in Washington.
W. W. McLaughlin, Irrigation Engineer, in charge of work in Utah.
P. E. Fuller, Irrigation Engineer, in charge of power investigations.
O. W. Bryant, Irrigation Manager, in charge of work in Colorado and Wyoming.
W. L. Rockwell, Irrigation Manager, in charge of work in Texas.
D. N. Bark, Expert, in charge of work in Kansas.

ASSISTANT IRRIGATION ENGINEERS.

V. M. Cone, H. I. Moore, and F. L. Bixby.

COLLABORATORS.

O. V. P. Stout, University of Nebraska, in charge of work in Nebraska.

Burton P. Fleming, New Mexico Agricultural College, in charge of work in New Mexico.

Gordon H. True, University of Nevada, in charge of work in Nevada.

Elias Nelson, Idaho Agricultural College, in charge of work in Idaho.

W. B. Gregory, Tulane University of Louisiana, in charge of rice irrigation in Louisiana and Texas.

Herbert T. Nowell, University of Wyoming, studies of duty of water in Wyoming.

IRRIGATION FARMERS.

John Gordon, R. G. Hemphill, W. H. Lauck, R. E. Mahoney, and John Krall, Jr.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., October 1, 1908.

Sir: I have the honor to transmit herewith a report of investigations carried on in southern California to determine the distribution within the soil of the water applied to orchards in furrow irrigation. This work is a part of a general study of the losses of water in irrigation and their prevention. In the section where these studies were made it seems that the limit of the water supply has been reached, while only a small part of the land has been reclaimed, and further extension of the irrigated area is possible only through greater economy in the use of the present supply.

To determine where losses occur and how they may be prevented has been the object of our work in that section for several years. A report of the losses of water into the air by evaporation and the effectiveness of various methods of checking these losses has been published (Bulletin 177 of this Office). The report now transmitted traces the losses into the soil beyond the reach of plants and suggests some remedies. It is recommended that it be published as a bulletin of this Office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS

Page.

Introduction 9
  Soil moisture 10
Observations on Block No. 58 11
  Preliminary examination 11
    Character of land 12
    Moisture content before irrigation 13
  Application of water to the orchard 16
  Movement of water in the furrows 16
  Percolation of water 17
    Percolation on the west side of the orchard 17
    Percolation in the central furrows of the orchard 22
    Percolation in the eastern furrows of the orchard 23
  Amount of water absorbed by the soil 23
    Middle section across sixteen furrows 24
    Section across lower end of west-side furrows 25
    Accumulation of water at lower end of the furrows 26
    Upper end of west-side furrows near the head ditch 27
    Summary for four west-side furrows 28
    Water in the soil six weeks after irrigation 29
    Absorption of water in east-side furrows 30
Observations in an orchard showing the effect of hardpan on water movements 32
  Upper end of furrows 34
  Middle part of furrows 35
  Lower end of furrows 36
  Amount of irrigation water absorbed 37
  Effect of hardpan 37
Observations of water movements in orchard No. 80 37
  Preliminary examination 38
  Application of water 39
  Volume of water from head ditch into the furrows 39
  Temperature of the water 40
  Percolation and absorption of water 40
    At the upper trench 40
    At the middle trench 41
    At the lower trench 42
    Water in the soil five days after irrigation 43
Percolation from shallow and deep furrows 44
Observations in the Mylne orchard 46
  Percolation of the water 48
    Progress of percolation 51
  Loss of water by evaporation 51
  Amount of irrigation water absorbed 52
  Amount present one month later 52
Observations in other groves 53
  The Beulah grove 53
  The Carscaden grove 54
  The Irving orchard 56
Conclusions 59

ILLUSTRATIONS.

Page.
FIG. 1. Outlines of percolation under sixteen furrows on west side of orchard 58. 18
2. Outlines of percolation under lower end of east-side furrows........... 23
3. Section across lower end of west-side furrows........................ 26
4. Curve showing probable lower limit of percolation from head to foot of west-side furrows... 29
5. Outlines of percolation where hardpan is near the surface.............. 35
6. Outlines of percolation where hardpan is near the surface.............. 36
7. Outlines of percolation where hardpan is near the surface.............. 36
8. Outlines of percolation at upper trench in orchard 80.................. 40
9. Outlines of percolation at middle trench in orchard 80................. 41
10. Outlines of percolation at lower trench in orchard 80.................. 42
11. Outlines of percolation from furrows 10 inches deep in seven hours..... 44
12. Outlines of percolation from furrows 5 inches deep in seven hours...... 45
13. Outlines of percolation in compact soil from furrows 8 inches deep..... 45
14. Outlines of percolation in Mylne orchard, upper trench................ 48
15. Outlines of percolation in Mylne orchard, middle trench............... 49
16. Outlines of percolation in Mylne orchard, lower trench................ 50
17. Outlines of percolation under four shallow furrows, Irving orchard..... 56
18. Outlines of percolation under three deep furrows, Irving orchard...... 57
19. Outlines of percolation under four deep furrows, Irving orchard....... 59

DISTRIBUTION OF WATER IN THE SOIL IN FURROW IRRIGATION.

INTRODUCTION.

Irrigation is practiced more generally in the valley of southern California than in any other part of the State; and because of the low rainfall, the large area under culture, and the continually increasing number of citrus orchards the orchardists are realizing the importance of either a greater water supply or some means of utilizing better the amount on hand. An increase of the supply seems to be improbable, for apparently all the available local sources have been developed. A more economical use of the available supply is then the only way in which new orchards and new fields may be provided for without injury to those at present in bearing.

The question of economy resolves itself into the following: What amount of water should an orchard have for best productiveness? What becomes of the water that is given to an orchard under the present irrigation practice? How much is lost to the plant or tree, and how may this loss be stopped?

It was decided at the beginning of this investigation to confine the work to determining what becomes of the water when applied to the land. This embraces the amount lost by surface evaporation and the extent in area and depth to which the water percolates beneath the furrows, as well as the proportion retained by the soil or available to the trees. The work on evaporation is reported on in another bulletin,[a] and this report contains the results of the studies of percolation.

In undertaking to solve these questions as far as possible by investigations in the orchards themselves we were handicapped at the very beginning of the field work by the fact that no observations had ever been made along this line on so large a scale. We could not therefore anticipate fully the problems and difficulties that might arise in the few days covering the irrigation period during which everything must be done. This investigation may therefore properly be regarded as a preliminary one, dealing as much with methods as with results.

---

[a] U. S. Dept. Agr., Office of Experiment Stas. Bul. 177.

The region of Riverside, in southern California, was selected as the field of investigation because of the special interest manifested in the results by orange growers and because a leading land company generously gave the use of its orchards, together with every facility in the matter of water and in part the labor. We were ably assisted by Messrs. J. E. Roadhouse, O. W. Bryant, and R. McL. Fortier in the field work and in the compilation of results.

The soils of the Arlington Heights property vary from a reddish sandy loam to a more clayey and more or less gritty loam, quite compact in texture. We chose for the main experiments and observations the orchard comprising block 58, thinking at the time that it represented the main portion of the red mesa lands of the valley, its soils being chiefly a sandy loam. Then, too, irrigation had already been begun on many of the orchards which might have been more desirable. Later in the season, when experiments on block 58 had been concluded, other orchards with a different soil were selected and similar investigations made, but on a smaller scale.

The furrow system of irrigation is used in the orchards around Riverside, some irrigators preferring five and others four furrows between tree rows. With five furrows the water is delivered to the land in greater volume and spreads laterally more rapidly and to a greater extent, and there is consequently a greater loss by evaporation. In orchard 58 the four-furrow system was used.

SOIL MOISTURE.

Water exists in the soil chiefly in two conditions, namely, hygroscopic and free, the former being that which is held as a thin film covering the surface of each grain of soil and not free to move except when vaporized by heat, while the free water is that which is free to move from place to place in soils, either by percolation under the influence of gravity or by capillarity under the influence of surface tension. The free water is alone to be regarded as of any value in promoting growth and productiveness, and in the following pages it alone is mentioned. Its movement is limited by the texture and water-holding power of the soil. The height to which it will rise above the source is controlled by the soil texture. The coarser the soil the less in height will water rise by capillarity. The depth of percolation for a given amount of water is limited by the water capacity and freedom of movement.

The soil beneath the furrows can be examined easily, and the results are often full of surprises for the irrigator. In some of the orange orchards in the regions of both Corona and Riverside it was found by examination that after a three days' run of the water it had reached a depth of only 10 or 12 inches, instead of several feet as it should have done.

OBSERVATIONS ON BLOCK NO. 58.

In this orchard tract, No. 58, of 10 acres the trees were 22 feet apart each way. The land was quite even in surface, well mulched, and had a gentle slope to northward from the head ditch to another irrigation ditch 660 feet distant, which was used to irrigate an adjoining orchard.

PRELIMINARY EXAMINATION.

Before water was applied to the land it was necessary to ascertain the character of the soil to a depth of several feet and the amount of water already present in the several feet, and in as many localities as possible throughout the orchard. As the time was short for such preliminary work it was found best to limit it to a series of holes made at intervals across the upper, middle, and lower sections of the orchard and to depths of 9 to 13 feet, although it was not anticipated that water from irrigation would penetrate deeper than 5 or 6 feet.

In this preliminary examination more than one hundred holes were bored and about one thousand samples of soil taken and the moisture content of each determined. The outfit for sampling the soils consisted of the following:

(1) An auger 4 inches in diameter. Its arm can be extended for any desired depth of boring by the addition of 4-foot sections of gas pipe, held together by small bolts, which prevent the joints, if screwed together, from becoming too tight.

(2) Wide-mouth 4-ounce glass bottles, provided with long corks, well paraffined to prevent the escape of moisture vaporized by atmospheric heat. It is well to have a supply of paraffin on hand to be melted and poured over the stoppers for additional safety.

(3) A broad-plate balance with maximum and minimum carrying capacity of 400 grams and 0.1 gram.

(4) One hundred or more ordinary wide tin pie plates, to be used for drying soils in the open air.

(5) A small or hand garden trowel.

(6) A small, light frame, 3 feet square, with fine wires stretched across at each 6 inches to aid in marking off coordinates on the face of the trenches for taking soil samples and for recording the wet outlines of progressing percolation of the irrigation water.

(7) A light, wooden frame box, 4 feet wide by 6 feet long, and of convenient height, covered on three sides with cheesecloth, and provided with shelves. The object of the box is to protect the balance from the wind while the operator makes the first weighings of bottled soils in the field. The bottle with the soil is weighed before opening, the soil then transferred to a tin plate for drying in the sun, or in a room if too much wind is blowing. When dry the soil and bottle are weighed together for loss of moisture and then the weight of the dry

soil ascertained by another weighing. The calculations for moisture percentages were based on the air-dried soil, which gives the free moisture, and not the hygroscopic, the latter being of no consequence in these investigations and requiring greater heat and greater time and trouble for its determination.

To ascertain the amount of irrigation water absorbed by the soil, trenches were dug across the furrows to a depth of 5 or 6 feet and of convenient width. Using the coordinate frame as a marker, samples of soil were taken with the trowel at a depth of several inches from the surface of the face of the trench, and at distances desired, usually 12 inches apart. These were bottled quickly and the moisture determined.

It is often desirable to express the water content in pounds or gallons, and for this the weight of a compact cubic foot of the soil was ascertained, and with this as a basis percentages were reduced to pounds or gallons.

In order to make the curves or outlines showing the movement of the percolating water at various times it was necessary to dig the trench before the water was turned on, and wooden troughs, made water-tight with pitch, were placed across the trench to connect the furrows. At regular periods during irrigation a thin slice of soil was cut from the face of the trench, exposing a fresh surface of the wet area, and with the frame coordinate marker the outlines were quickly recorded. The trenches were left open for several days after irrigation had ceased, so as to record any additional movement of the water.

CHARACTER OF THE LAND.

The soil of the orchard is a sandy loam of good texture, more or less micaceous and granitic in origin, being derived from the hills on the south, in which are great masses of granite composed of quartz, orthoclase feldspar, and biotite or black mica. The soil throughout the tract is underlain by a highly micaceous and more or less gritty loam at depths varying from 2 to 5 feet, as was shown by the preliminary examination. The grit consisted of small fragments, partly granitic, with its minerals still intact, and of single grains of feldspar and quartz loosened from the rock by weathering agencies. It is irregularly distributed, sometimes in pockets or small bodies of little else than grit inclosed in the loam. Occasional pieces, the size of gravel, of either granite, quartz, or feldspar were met with in the examination. Still deeper down this mixed loam and grit is underlain by a bed of almost pure grit of the same character, and reaching in places many feet in thickness.

The beds of grit are nearer the surface in the southeastern portion of the orchard, which is nearest a high hill of granitic rock, to which the land slopes. Here the coarse grit is within 3 feet of the surface, while on the west it appears only at 7 to 9 feet.

In the lower part of the orchard the overlying loam is thicker than on the northeast and the coarse grit beds are deeper below the surface. These grit beds give to the land excellent underdrainage toward the lower plains on the north, and in the case of storms or excessive irrigation will prevent stagnation of water and consequent injury to the soil and roots of trees. It is believed by many of the orchardists of the Riverside region that water is thus lost from orchards and leaky ditches, as well as from head ditches constructed in the soil without cement protection. The gritty material often forms very compact beds—so much so that in many places the auger failed to penetrate them. With the loam the grit forms a kind of hardpan, especially in the eastern half of the orchard tract. It is, however, not wholly impervious to water, for water loosens it quickly and affords easy penetration to the tree roots. On drying, it again becomes hard and firm and may prevent proper aeration of the soil below. The western half of the orchard has not this hardpan. A soil of this nature has but a low capacity for holding water, and the maximum capacity or saturation point of this was found to be 38 per cent of its weight.

The weight of the sandy loam of the orchard, No. 58, which was ascertained in order to determine the amount of water in the soil, was 110 pounds per cubic foot when well compacted. In a loose condition (such as mulch) the weight was 92 pounds per cubic foot.

The thickness of the upper sandy loam varies from point to point. Beginning on the southeast, in the upper part of the orchard, we find in passing westward that the surface of the underlying grit forms a waving line, 2, 3, and 4 feet below the surface for a distance of 525 feet, then sinks to 6 feet, and deeper to the end.

Across the middle of the orchard from east to west it was found to be farther below the surface and in a waving line of 4 to 5 feet, rising in one place to 3 feet. Across the lower part of the orchard the depth of the loam soil is still more irregular, beginning with 3 feet, soon sinking to 4 feet, then to 5 feet at 200 feet distance, varying between that and 3 feet until, at 410 feet the soil bed assumes a thickness of 8 to 9 feet above the grit. The deepest bed of loam is therefore on the northwest and west.

MOISTURE CONTENT BEFORE IRRIGATION.

The last application of water previous to the experiments was in October, 1904. In the following winter there was a rainfall of 16 inches (as recorded by the foreman of the ranch) and at one time a flood of water from the south poured in over a portion of this orchard. By the latter part of June, after a lapse of several months, the total quantity of water in the soil to a depth of 13 feet was the equivalent of a depth of 15.7 inches over the surface, as ascertained by the many examinations made at that time.

While the full detailed results of these determinations might be of some interest, it is not thought necessary to present, in the following table, more than a general summary of the average moisture content in each foot of depth across the respective upper, middle, and lower (east and west) parts of the orchard to a depth of 13 feet.

Average percentages of soil moisture before irrigation.

Depth.	Upper line, 30 holes.	Middle line, 33 holes.	Lower line, 38 holes.	General average, 101 holes.
Feet.				
1[a]	2.90	3.40	3.90	3.40
2	3.25	3.61	4.27	3.71
3	5.30	5.13	5.15	5.19
4	6.28	6.12	6.84	6.41
5	6.56	6.49	6.45	6.50
6	5.89	6.37	6.43	6.23
7	4.79	5.85	5.87	5.50
8	6.95	5.61	6.33	6.29
9	7.56	6.47	6.18	6.73
10	5.08	6.50	6.26	5.95
11	5.97	6.98	4.78	5.91
12	6.54	5.96	6.03	6.18
13	7.63	6.71	6.22	6.85
Average	5.75	5.78	5.75	5.76

[a] Mulch.

These columns of averages show quite an even distribution of free water below the upper 2 feet, throughout the orchard, to a depth of 13 feet, the general averages per horizontal foot in the column varying from 5.19 per cent in the third foot to 6.85 in the thirteenth foot, the average of the whole 10 acres to a depth of 13 feet being 5.76 per cent; or, if the upper 2 feet are excluded, 6.16 per cent. This is equivalent to 4,284,000 gallons of water for the 10 acres, or a depth of 15.7 inches over the surface. The greater part of this was below the reach of the roots and hence of no immediate benefit to them, emphasizing the advantage of bringing about deep penetration of the roots. It is perhaps quite remarkable that the general averages for the three sections of the orchard—upper, lower, and middle—should represent so very nearly the same average percentages (5.75, 5.75, and 5.78) throughout, in spite of the fact that in individual borings there were so often such great differences between adjoining feet of the same column.

The preliminary examination for moisture content in the orchard gave the following results:

The surface mulch varied from 6 to 8 inches in depth and was loose and dry. The examination of samples from several points in the orchard showed very little or no free moisture. Evidently the little that rose from below into the mulch by capillarity was vaporized by the high heat of the soil, leaving only a little hygroscopic moisture.

The soil immediately below the mulch, which completed the first foot in depth, showed by the darker tint some free moisture, varying in amount in each hole dug. The lowest percentage was 1.63 and the highest 5.68 per cent. The driest soils were along the upper part of the orchard, the general average of the first foot being 2.9 per cent. The next were in the middle, with an average of 3.4 per cent. The lower part of the orchard shows higher percentages, averaging 3.9 per cent. The reason for these progressive differences is not apparent. We again found that the amounts in the first foot were, in general, less in the eastern than in the western half of the orchard, the averages being, respectively, 3.2 and 3.6 per cent. The general average for the first foot for the whole orchard is 3.4 per cent.

One of the most striking results of the preliminary examination was the great variation in the amount of water, not only through the orchard from place to place, but from foot to foot, in each soil column itself to depths of 13 feet. We would naturally expect to find at least some near approach to uniformity in the soil after the several months that had elapsed since the last rainfall; not the same percentages from the surface down, but a gradation downward from low to higher, and rising to a maximum in the lower depths. Naturally we find, as a rule, that the lowest percentages are in the upper two feet because of the evaporation; we usually find from 2 to 4 per cent in the soil just below the mulch and a little more in the second foot. Then in the next foot there is usually an increase of 1 or 2 per cent and sometimes as much as 4; and in 66 cases out of 93 examinations another increase of 1 to 5 per cent in the fourth foot. On the other hand, there is frequently a sudden diminution in the amount of water found in passing from one foot to that immediately below—a difference in some instances of several per cent.

These abrupt and large differences may be accounted for in several ways: (1) Capillary movement upward; (2) differences in texture of the soil; and (3) absorption by tree roots.

Sometimes the grit layer at depths of 8 or more feet was found to be very moist to an extent beyond natural field capacity; the excess was doubtless seepage from the irrigation water in orchards above, on the slope of the mesa. It was much more noticeable on the eastern side of the orchard, where the thick bed of coarse grit was penetrated, and in the lower portion of which we usually found 10 to 14 per cent of water.

At similar depths on the west in the gritty loams the percentages of 4 to 6 per cent were usually maintained. Here the bed of coarse grit occurred at a lower depth than was reached by the auger, and no doubt the flow of waste water would have been reached in the lower portions.

It is well known that plants and trees all draw their moisture supply from the soil by means of the microscopic root hairs which cover the ends of the fine rootlets, and not through other parts of the root system, which are covered with a bark that is impervious to water. We would, therefore, naturally expect to find the soil surrounding the rootlets to have a lower percentage of moisture than that away from them. This has frequently been found to be the case with trees of all kinds, and to this action of the rootlets may be attributed many of the instances of low-moisture content.

The maximum depth of penetration by the roots, observed in this orchard, was about 6 feet, but only as a rare exception. The great mass of feeding roots kept within 4 feet of the surface, though frequently they occurred in a mass in the upper 2 feet.

APPLICATION OF WATER TO THE ORCHARD.

Water was turned into the head ditch July 7 through a Cipolletti weir. The flow was carefully measured from time to time by Mr. J. E. Roadhouse during the three days' run for each portion of the orchard, and maintained at a rate of 35.5 inches under a 6-inch head. The orchard irrigator was instructed to follow his usual method of controlling the flow from the head ditch into the furrows, opening at first the small holes at the lower end and allowing the water to enter the furrows of that part of the orchard where these special observations were made.

MOVEMENT OF WATER IN THE FURROWS.

The depth of water in each furrow was not more than one-half inch, and its advance movement down these furrows was very slow at first, because of easy percolation into the soil both downward and sidewise and saturation of the soil to a few inches in depth. The furrows were shallow and the water spread quite rapidly sidewise through the mulch, and soon the greater part of the space between the furrows was wet on the surface.

The water moved slowly in these furrows, requiring about five hours to reach the middle, a distance of 330 feet, and about twelve hours longer to reach the end, a distance of 330 feet more. During the day the advancing column of water was frequently checked and even made to disappear for many feet in the rear because of vaporization by the hot soil and air. When once the water reached the end of the furrow the flow was continuous as long as supplied from the head ditch.

Measurements of the rate of flow at several points in a furrow were made by Doctor Fortier, and gave the following results:

Measurements of the flow of water in furrows.

Location.	Gallons in one minute.	Gallons in one hour.
Feet.		
Upper	7.50	450
165	4.30	258
230	4.30	258
495	2.10	126
650	.85	51

It is thus seen that the volume of flow diminished to nearly one-half in the first quarter and at the middle, to nearly one-fourth at three-fourths the distance, and to nearly one-ninth near the end.

PERCOLATION OF WATER.

In order to study the various phases of the percolation of irrigation water from furrows, it was thought best to dig trenches across some of the typical furrows before the water was turned on, a wooden trough being placed across the trench to conduct the water over to the lower portions. Then from time to time the face of each trench could be cut back and a fresh surface of the wetted soil exposed, the trough being moved back a few inches each time.

PERCOLATION ON THE WEST SIDE OF THE ORCHARD.

Sections across middle of sixteen furrows.—A trench 90 feet long, reaching across five tree rows and sixteen irrigation furrows, was dug east and west on the west side of the orchard and only halfway down the furrows. The width of the trench was 3 feet, or only sufficient for a comfortable working space, and its depth was 6 feet. As percolation of the water progressed, the freshly wetted area was clearly defined by the darkening of the color of the soil, and was easily outlined with the coordinate wire frame and recorded on coordinate paper. The accompanying diagram (fig. 1) shows the curves produced by the water as it moved downward and laterally from the bottom of each furrow. The furrows are numbered from left to right, each group of four occupying the space between two tree rows.

These outlines, covering as they do the spaces between five tree rows with their sixteen furrows, are very instructive, and there are a number of points which should be noted: Irregularity in outline, inequality in depths of percolation in different periods of time, and the wide areas of dry soil between the wetted areas.

Perhaps the first point that attracts the eye is the great irregularity in the outlines of the curves, some sinking to 5 feet and others to 3

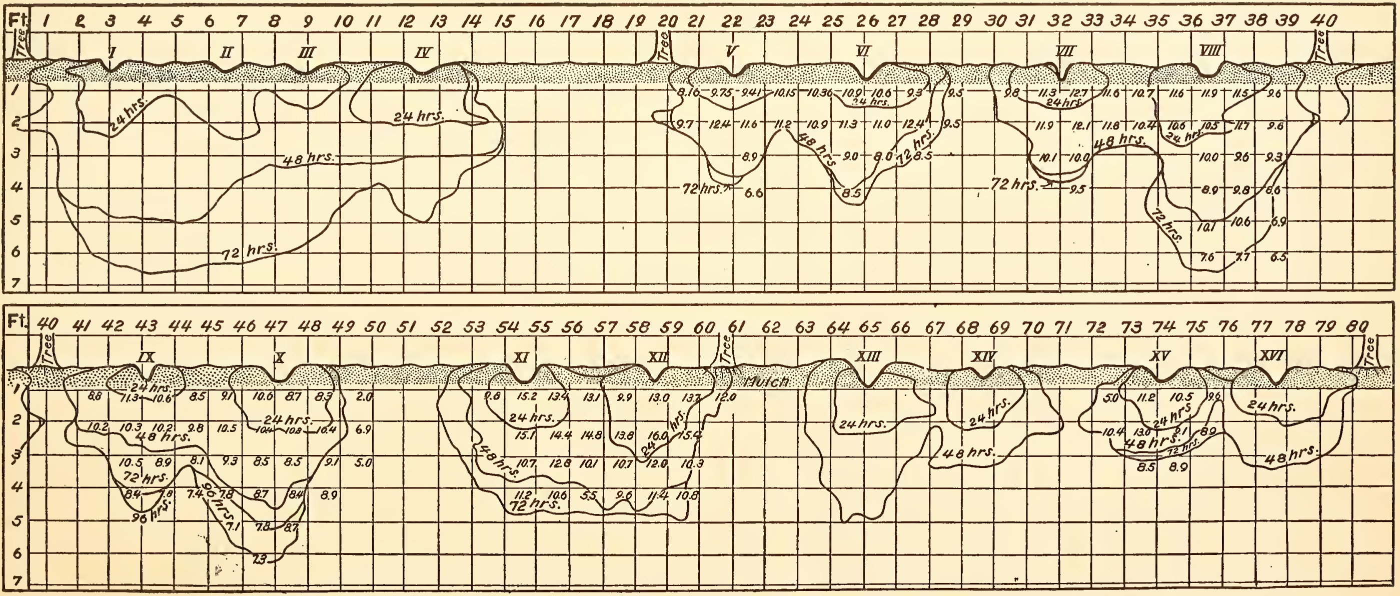

Fig. 1.—Outlines of percolation under sixteen furrows on west side of orchard 58.

feet, and some spreading laterally more than others. These irregularities may be explained by the differences in soil texture and compactness, differences in the depths and widths of furrows, etc.

The vertical wet areas are isolated in groups, the water frequently failing to spread sidewise sufficiently to meet between furrows. In fact, in this trench the furrows are paired off, two furrows uniting their waters after the lapse of twelve or more hours. In two places only does this union take place in less than twenty-four hours, and in these it seems to be due to a compactness of the underlying soil which, by resistance, allowed the water to move sidewise. In only one instance do we find the four furrows between the trees giving a solid wetted area. This isolation is in part due to differences in distance between furrows and in part to the tendency to move downward faster in the center and thus contract the side lines. The furrows had been made with a "marker" with two narrow shovels 4 feet apart, and as it passed down the row and back the two furrows on either side were of course the same distance apart, while the spaces between the pairs and across the tree row on either side were very irregular.

The fact that the water percolates laterally only 2 or 3 feet from the furrow and fails to reach entirely through the tree row under the soil surface comes rather as a surprise to irrigators, for it is generally thought that, while the surface soil may not be wetted, the movement of the water is outward as well as downward, and that at a short depth below the surface the entire soil body from tree to tree has received water. But the present observations in this and other orchards show conclusively that in a soil where there is no compact substratum to stop the percolation of water downward the movement is greatest underneath the furrow and less and less on either side, the curve produced being irregularly conical; and that where an obstructing layer, such as hardpan, occurs the movement is sidewise over it; and that when a bed of grit is encountered the movement is also more rapid, because resistance is greater in the soil than in the grit. This was seen at a number of points.

It appears that the width of dry soil enlarges as the depth increases. This is shown in the following table, in which the relative areas of wet and dry soil in each foot across the face of the long trench to the depth of water penetration are given:

Relative areas of wet and dry soil on the face of the 80-foot trench.

Depth.	Area of wet soil.	Area of dry soil.	Percentage of wet soil.
Feet.	*Square feet.*	*Square feet.*	*Per cent.*
1	62	18	77.50
2	63	17	78.75
3	57	23	71.13
4	32	48	40.00
5	22	58	27.50
6	4	76	5.00

In the first 2 feet, because of the wetting of the soil by lateral percolation, we have a little less than 25 per cent of the soil untouched by the water. Then the wetted surface under each pair of furrows contracts rapidly and leaves 60 per cent untouched in the fourth foot. Under some of the furrows the water does not penetrate into the fifth and sixth foot. From the surface down through the fifth foot, or to the usual depth of root area, the proportion is 61 wet to 39 dry.

These curved outlines of the wet soil changed somewhat during twenty-four hours after the water was cut off from the furrows, but there was scarcely any movement afterward except, perhaps, of the water within the curves at points where there was more than the soil could hold by capillarity.

It would be supposed that the presence of so large an amount of soil not reached by the irrigation water would have some effect on the development of the root systems of the trees, causing a larger mass of fine roots to be found beneath the furrows where the water is most abundant. This, however, was not observed in the trench, and fine rootlets appeared in the walls of the trench throughout. In spite of the fact, however, that irrigation water failed to wet the tree row there was quite a percentage of water present from the rainfall of the previous winter, sufficient to maintain life and health in the tree, and this may also have been sufficient to produce root development here.

When water passes into a furrow it is quickly absorbed by the soil below and on the sides, and if the soil is loose the movement away from the furrow is rather rapid. In the meantime it is also drawn up by capillarity toward the surface and unless that surface is 10 or 12 inches above the flowing water it reaches it and is then subject to evaporation. It is almost universally the case that the furrow spaces between the trees are wet throughout, with a dry spot only here and there, and in the tree row.

Irregularity in depths of percolation during regular periods of twenty-four hours each is well shown by the curves in figure 1, page 18. It will be seen that during the first twenty-four hours water penetrated to depths varying from 6 to 30 inches below the bottoms of the furrows, the general average for the sixteen furrows being 17.6 inches. In four of the furrows the depth reached was 24 inches, and in six others 18 inches. The cause of these differences lies probably in the more or less compact condition of the soil beneath the furrows, though in the former case there would be a greater seepage to either side, which does not appear in the case of the 6-inch depth. The wide lateral seepage with shallow penetration is shown beneath furrows V and VI, the waters from which united to form a continuous wet area 7 feet in width and 12 inches in depth. For the next twenty-four hours the general average of additional percolation was 21 inches, or 3.4 inches more than for the first period. In nine of the furrows the movement was faster than for the first twenty-four hours, in one it was the same, while in others it was slower, the two extremes being 32 and 8 inches. In four of the furrows there was no further percolation after this time. In the twenty-four hours succeeding the forty-eight the differences in movement were very great, there being in some a penetration of but 3 inches, while in others it reached 18 and 24 inches. Percolation practically ceased at the end of this time, which also marks the time when the water was cut off from the furrows, except in furrows IX and X, where the water continued to soak down for a few hours longer and added another 6 and 12 inches to the depth. The greatest depth reached in these sixteen rows was 72 inches in the center and also on the extreme right of the cross trench; but here the percolation was influenced by the presence of a bed of coarse grit with its more open texture. The general average depth for all was about 46 inches. These irregularities, and in many cases shallow percolation, illustrate the great importance of ascertaining the movements of water beneath the furrows during irrigation.

Relative increases in wetted areas during successive periods.—Water in percolating downward does not follow direct lines beneath the furrow but moves forward along lines of least resistance, faster at some points than at others, and sidewise as well as downward. We, therefore, naturally find the wet vertical areas shown on the face of the trench to be very irregular in form from one period to another. Taking them in groups as shown in the diagram (fig. 1, p. 18) we find the following increase of area for the several periods of twenty-four hours each:

Increase of wet areas in successive periods of time.

Time.	Furrows.						
	I to IV.	V to VI.	VII to VIII.	IX to X.	XI to XII.	XIII to XIV.	XV to XVI.
Hours.	*Sq. feet.*	*Sq. feet.*	*Sq. feet.*	*Sq. feet.*	*Sq. feet.*	*Sq. feet.*	*Sq. feet.*
24	19.50	6.25	9.50	7.25	10.25	8.00	8.00
48	32.25	13.50	20.00	16.00	15.50	14.25	9.50
72	17.25	3.00	6.00	4.25	5.25	....	1.25
96	....	....	....	3.00	....	....	....
Total	69.00	22.75	35.50	30.50	31.00	22.25	18.75

It would naturally be supposed that because of the easier movement of the water and the easier displacement of the air of the soil near the surface the water would in twenty-four hours spread downward through a greater area than in the succeeding twenty-four hours, but the reverse is seen to be true, and in every instance in the table the area is greater in the second than in the first period, in three cases being more than double. The reason of this is probably the difficulty with which the water penetrates through the compacted soil beneath the surface mulch during the first period, and the easier movement after this had been saturated with water. The total wet area under each group of furrows varies from a maximum of 35.5 to a minimum of 18.75 square feet and with an average of about 29 square feet per group, or 58 square feet for each space of four furrows.

Lateral seepage from the furrows.—The general extent of lateral seepage from these furrows in the first twenty-four hours was about 18 inches. In the first three furrows and in furrows V and VI the entire interspaces were wetted in the first twenty-four hours, while in all of the other groups of two furrows each the spaces became wet only in the next twenty-four-hour period.

It is worthy of note here that in two cases where the furrows were deeper than elsewhere the water did not reach the surface in the first twenty-four hours as it did from all of the shallow ones. The extreme distance from the furrow reached by the water was 3 feet and the average was about 2.5 feet.

Percolation in the lower and upper parts of these furrows.—In the lower portion of the west-side furrows and about 30 feet from the end a short trench was dug after irrigation water had been cut off. It was found that the water had penetrated to a depth of about 4.5 feet below the bottoms of the furrows, with a spread of 2 feet on either side of the two furrows. There was the usual irregularity in the curve, the same tendency to turn inward on the sides, the same upward curve in the lower center between the furrows, and the same dry soil in the tree rows on either side of the wet space, as found elsewhere. The vertical area on the face of the trench made wet by the water was 33 square feet.

It was found by trenching and boring seven days after the water had been cut off that in the upper part of these westerly furrows, about 30 feet from the head ditch, the water had reached the grit stratum at 6 feet and had passed readily into it to a depth of 26 feet from the surface. On either side it had nevertheless failed to reach the center of the tree row.

PERCOLATION IN THE CENTRAL FURROWS OF THE ORCHARD.

No observations were made near the head ditch in the center of the orchard, but doubtless the water had penetrated as many feet as on the west. A trench dug across the middle of four furrows two days after irrigation had ceased exposed a bed of gritty clay at 6 feet, which was very hard and compact when dry, but yielded to and absorbed water easily. The surface soil was wet entirely across the four furrows and 2 feet on either side, a distance of 13 feet in all. In its passage downward the water moved slightly outward, following gritty clay, and to a depth of 8 feet. Near the lower end of these furrows borings showed that the water had penetrated to a depth of 8 feet, while still nearer the end and where the excess of water had been caught the auger showed mud at 13 feet.

PERCOLATION IN THE EASTERN FURROWS OF THE ORCHARD.

In the lower second space of the northeastern part of the orchard the soil is more compact than elsewhere and water was found to percolate more slowly. The accompanying diagram (fig. 2) shows the outlines of penetration of the water downward across four furrows. The maximum depth reached in forty-eight hours was 4 feet below the bottom of furrow I, and 2.5 feet below furrow II, and as usual was greater just below each furrow than between them. The water spread to 2.5 feet on each side of the furrows, but failed to reach across to the other two furrows of the group, there being 1 foot of dry space between them. The earth beneath the wet portion was found to be very hard and compact and scarcely yielded to the pick. The wet surface on the face of the trench presented the typical ox-yoke features, and covered an area of 25 square feet. The other two furrows of the group have a smaller penetration, the water seeming to pass through the hard earth with less ease. The maximum depth reached was 2 feet and the total wet vertical surface was 9.2 square feet.

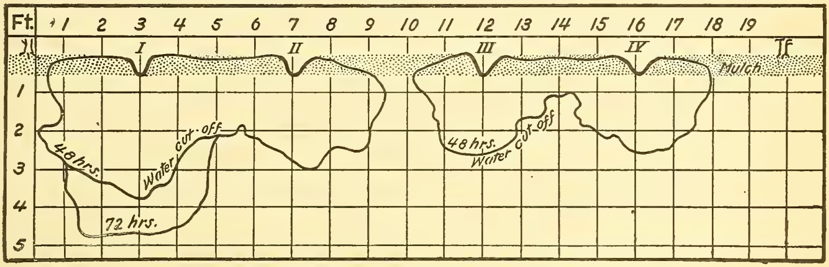

FIG. 2.—Outlines of percolation under lower end of east-side furrows.

AMOUNT OF WATER ABSORBED BY THE SOIL.

The determination of the amount of water retained by the soil of the orchard was a difficult matter because of its large area, the rapidity with which we had to work, and the slow process of taking, weighing, drying, and reweighing the samples of soil. The only feasible method was to concentrate the work upon only a portion of the orchard and take coordinate samples from a vertical section, such as that presented by the long trench in the middle of the western furrows of the orchard.

MIDDLE SECTION ACROSS SIXTEEN FURROWS.

The long trench that had been dug across the middle of the western furrows was taken as the basis of observations on the amount of water absorbed from irrigation; in other parts of the orchard examinations were made afterwards to determine whether the results were typical.

The figures in the diagram (fig. 1, p. 18) showing outlines of percolation give the total percentages of free moisture in each foot. They strongly illustrate the irregularity of absorption in the soil, even at nearby points at the same depth. We would naturally suppose that there would be more water immediately beneath the furrows than in the intermediate portions, but we find that this is not always the case except in the first foot, and even there not without exceptions. We see, too, that the highest percentages are for the most part in the second foot. This irregularity in freshly wetted soils shows that it would be unwise to assume that a hole bored at any point is representative of conditions under the two furrows. The better method for comparison is to take the average water percentage in each square foot beneath each group of furrows and from that deduct the average found before irrigation. This will give the percentage actually absorbed from the irrigation water. In the following table the average percentage in each square foot for each group of furrows is given in the first column, while the second column is the excess above that present before irrigation. In Nos. I to IV, XIII to XIV, and XVI the moisture contents were not determined:

Percentages of water absorbed under irrigation furrows.

Depth.	Furrows.									
	Nos. V-VI.		Nos. VII-VIII.		Nos. IX-X.		Nos. XI-XII.		No. XV.	
	Total in soil.	From irrigation.	Total in soil.	From irrigation.	Total in soil.	From irrigation.	Total in soil.	From irrigation.	Total in soil.	From irrigation.
Feet.										
1	9.83	6.10	11.17	7.44	9.62	5.80	10.06	6.24	9.07	5.03
2	11.12	7.00	11.06	6.95	10.26	5.26	13.20	8.20	10.32	6.30
3	8.59	2.97	9.80	4.18	8.97	4.97	9.69	5.69	8.67	3.83
4	7.56	1.48	9.20	3.12	6.94	3.05	9.38	5.49		
5			9.18	3.68	7.83	2.57	7.77	2.51		
6			7.23	2.39	7.33	2.21	6.97	1.85		
7			7.55	2.98			6.13	2.23		
Average	9.28	5.43	9.31	5.36	8.49	4.54	9.03	4.99	9.35	5.37

The total amount of water in the soil after irrigation was nearly the same for each of the groups of furrows except Nos. IX and X, in which it was much smaller. The general average of total water in the soil was 9.05 per cent, and of this 5.14 per cent was received and held from irrigation water under the nine furrows.

It will be seen that in nearly every case there is more water in the second foot than in any other part of the column. This is probably due to evaporation of the moisture from the surface soil. As we go deeper we find that the percentages become less and less until at the bottom there is but little more than was present before irrigation began. These averages show the percentages held in the soil at the end of twenty-four hours after irrigation had ceased, and do not take into account the loss by evaporation from the surface which had occurred in the meantime.

The average weight of this soil per cubic foot loose and compact was ascertained by Mr. Bryant to be 92 and 110 pounds, respectively. Upon the latter weight we base the calculations of amounts of water in pounds, and in gallons as given in the following table. The general average of absorption for all the furrows of this middle section is 5.14 per cent. Assuming that the wet soil of the other furrows absorbed the same percentages we obtain the following table of results for a 1-foot section through the wet area across the sixteen furrows:

Water absorbed under the sixteen furrows in a 1-foot section.

Furrow No.	Area wetted.	Water absorbed.		
	Square feet.	*Per cent.*	*Pounds.*	*Gallons.*
I-IV	69.0	5.14	389.9	46.7
V-VI	22.5	5.43	134.4	16.1
VII-VIII	35.0	5.36	206.2	24.7
IX-X	30.5	4.54	152.0	18.2
XI-XII	31.0	4.99	169.5	20.3
XIII-XIV	22.3	5.14	126.1	15.1
XV-XVI	19.0	5.37	111.9	13.4
Summary	229.3	5.14	1,290.0	154.5

In the 1-foot section across the sixteen furrows there was therefore present, twenty-four hours after irrigation stopped, only about 154.5 gallons of water over and above that previously present and that lost by evaporation during the three days of irrigation. This was distributed through 229.3 cubic feet in varied proportions, the extremes being 24.7 gallons under the two furrows VII and VIII, which had the largest percolation, and 13.4 gallons under furrows XV and XVI, which had the least. These differences in the amounts absorbed were due chiefly to the forms of the furrows. Under those that were wide at the bottom and permitted of a spreading out of the water the soil received more water, and percolation was greater than where the furrows were narrow.

SECTION ACROSS LOWER END OF THE WEST-SIDE FURROWS.

A trench (fig. 3) was dug across two of these furrows 50 feet from the lower end of the orchard, twenty-four hours after irrigation had ceased. The measurements showed a wetted area of about 33 square feet, the outline being very irregular, as elsewhere. The water had flowed over this in the furrows for only about twenty-four hours, the excess being received nearer the end of the orchard.

The total amount of free water found in the 1-foot section was 9.40 per cent, but of this 5.27 per cent was present before irrigation water was applied, thus leaving but 4.13 per cent as that absorbed. This is equivalent to 150 pounds of water for the 1-foot section across the two furrows, or 300 pounds for the four furrows. The percentages of total water at this lower trench are shown in figure 3.

ACCUMULATION OF WATER AT LOWER END OF THE FURROWS.

The excess of water passing over the furrows to the end was received in many cross furrows and ditches, and was thus well distributed over the entire space between the trees and allowed to soak down, though much was lost by evaporation. This was in the lower 20 feet of the furrows. A boring made eight days after irrigation showed the presence of the following percentages in each foot down to 14 feet, the soil being still almost saturated with water at the bottom:

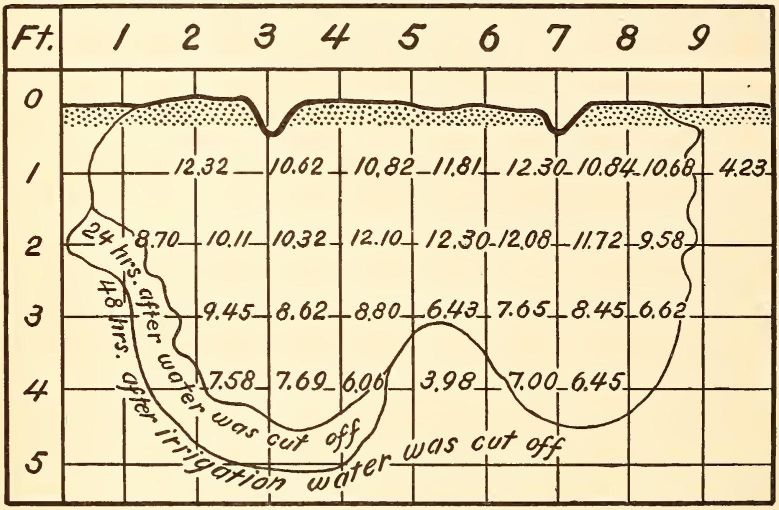

FIG. 3.—Section across lower end of west-side furrows.

Percentage of water at end of furrows.

Depth of hole.	Kind of soil.	Total after irrigation.
Feet.		*Per cent.*
1	Loam	9.88
2	do	11.72
3	do	9.43
4	do	7.17
5	do	8.16
6	do	8.25
7	do	8.38
8	Grit	5 20
9	Coarse grit	9.76
10	do	11.17
11	do	11.15
12	do	9.85
13	do	11.52
14	do	10.50

The general average of these percentages is 9.44. There was in the soil previous to irrigation 4.15 per cent of water, thus leaving 5.29 per cent as that held from the application of water. This would mean the absorption of at least 4,300 gallons or 36,000 pounds in the 14 feet depth. It is very evident, however, that this does not indicate the entire amount, and that much more passed down deeper in that coarse, gritty mass.

UPPER END OF WEST-SIDE FURROWS NEAR THE HEAD DITCH.

The long time in which the water remained on the soil near the head ditch during irrigation made us suspect that there was deep penetration at that point, and in order to ascertain the facts a trench 18 feet long (across four furrows, reaching from tree to tree) and 10 feet deep was dug seven days after the water was cut off. The distance from the trench to the head ditch was about 30 feet. This trench reached a thick bed of coarse grit and the soil and grit were evidently wet from the irrigation water; the wet area reached nearly to the tree row on either side. The auger was then resorted to, and with proper extensions reached a depth of 30 feet from the surface, passing into the coarse grit, but failing to reach its lower limit. The grit was wet to the bottom of the twenty-sixth foot, when it became drier, the percentage falling from 9.13 to 5.88 and then to 3.75 and 3.79, showing that the limit of percolation of irrigation water had been passed at 26 feet.

A 1-foot section across four furrows at this place gave a wetted column of about 468 cubic feet, reaching nearly from tree to tree, or 18 feet, and to a depth of 26 feet. The distribution of free water was very irregular, as in other trenches. The following table gives the percentages in five columns, several feet apart. The entire area was wet and no curves were shown at this time:

Percentages of water in section near head ditch, in columns several feet apart.

Depth.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Feet.					
1	6.23	6.74	5.17	5.75	1.79
2	6.58	6.40	5.75	8.31	6.27
3	7.09	4.90	6.28	8.03	6.28
4	6.57	6.17	7.30	11.08	6.75
5	12.90	10.40	10.55	5.40	6.54
6	4.42	4.63	6.84	10.82	10.91
7	....	....	9.28	12.50	....
8	....	....	13.86	13.01	....
9	....	....	8.60	10.22	....
10	....	....	10.26	6.07	....
11	....	....	4.56	9.04	....

The differences below the level of the third and fourth foot were largely due to pockets of grit and clay layers. The auger boring was continued to 30 feet under column No. 4, with the following percentages of free water:

Percentages of free water in section near head ditch.

Feet.	Per cent.	Feet.	Per cent.
12	9.63	22	11.50
13	14.85	23	9.06
14	8.89	24	11.20
15	7.32	25	5.13
16	9.72	26	9.13
17	10.72	27	6.82
18	10.06	28	5.88
19	11.26	29	3.75
20	8.33	30	3.79
21	5.53		

The 468 cubic feet comprising the wetted 1-foot section was found to have an average of 9.20 per cent of free water. Of this there was an average of about 5 per cent before irrigation was applied, thus leaving 4.20 per cent as that absorbed from irrigation. The 4.20 per cent is equivalent to about 259 gallons, or 2,162 pounds of water in 468 cubic feet.

SUMMARY FOR FOUR WEST-SIDE FURROWS.

We thus have in the 1-foot sections across four furrows of the upper, middle, and lower parts the following vertical areas wetted and water absorbed from irrigation:

Summary of water absorbed in sections across four furrows.

Location.	Area.	Free water.		
	Square feet.	*Per cent.*	*Gallons.*	*Pounds.*
Upper	468.0	4.20	259	2,162
Middle	57.5	5.40	41	342
Lower	66.0	4.13	36	300
End (levees excess)	310.0	5.39	220	1,837

It will thus be seen that the vertical section of the wet soil of the upper portion of the furrows, 30 feet from the head ditch, was nearly four times the size of that of the middle and lower portions combined, and that it held nearly 3.5 times the volume of water. The probable lower limit of wet soil is shown in figure 4.

The form of the curve made by the wet soil from the head of the furrows to the middle should have been ascertained by numerous borings along the line of the furrows, but its importance was not recognized and it was overlooked in the rush of work elsewhere. The actual depth of percolation was found to be 26 feet at a distance of 30 feet from the head ditch, but no borings between this and the point half way down the furrows were made; we therefore can only judge that the curves marking the percolation of a flow that was continually becoming less in volume as it progressed was a regular upward one from a point not far below the upper trench. But, on the other hand, experiments made on a small scale with this soil gave a curve that ascended quite abruptly toward the surface, as shown by the dotted line in the diagram, toward a point at one-fourth the length of the furrows. This agrees with the tests made by Doctor Fortier, who found that the flow of water at 165 feet from the head ditch was about the same as that at 330 feet and a little more than one-half of that at the head.

It is plain, then, that in the furrow system of irrigation the water is not evenly distributed throughout, but is largely held by deep percolation at the upper end, if there be free and ready movement downward; and also at the lower end where the excess of overflow is accumulated.

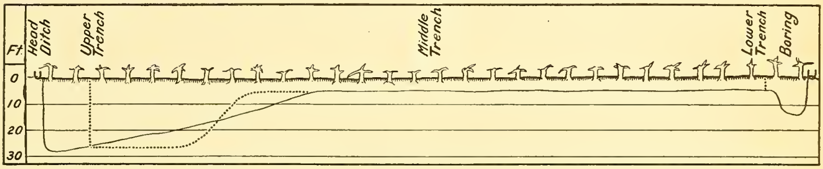

FIG. 4.—Curve showing probable lower limit of percolation from head to foot of west-side furrows.

WATER IN THE SOIL SIX WEEKS AFTER IRRIGATION.

The examination of the soil preliminary to irrigation was made in the last of June, water was applied on July 7, and on August 15 other examinations were made at several points in the westerly furrows of orchard No. 58 to ascertain moisture conditions and what changes had occurred. The results of the first and last examinations are given in the following table:

Percentages of water in the soil before and after the July irrigation.

	Upper.		Middle.		Lower.	
	June.	August.	June.	August.	June.	August.
Feet.						
1	3.93	1.94	2.32	3.80	4.18	2.13
2	3.82	1.94	4.53	4.65	3.76	3.75
3	4.84	4.84	4.79	5.09	5.12	4.80
4	3.98	5.71	5.14	5.07	4.70	4.07
5	4.54	8.98	5.46	6.01	4.14	4.67
6	3.52	3.42	4.68	5.78	4.56	3.78
7	8.75	6.92	3.82	5.02	3.60	3.30
8	4.71	5.77	4.77	4.09	4.43	3.17
9	4.26	11.42	6.46	6.12	2.92	11.26
10	3.46	7.97	13.10	11.55	7.36	9.81
11	6.50	8.76	8.65	9.32	7.54	7.86
12	6.22	4.79	5.14	5.57	7.14	8.22
13	6.20	5.83	5.70	6.51	....	....
Average.	4.70	6.02	5.72	6.04	4.96	5.57

From the table it will be seen that in the upper part of the furrows there remained only 1.32 per cent, in the middle part 0.32, and in the lower 0.61 per cent of the water that was applied or 0.75 per cent in the whole length of the furrows in a depth of 13 feet. This is equivalent to only about one-fifth of the water that was applied by irrigation. In the upper 3 feet of the soil as a whole there was a heavy loss; in the sixth and eighth feet there were also losses. The mulch given to the soil after irrigation was not sufficient to prevent the loss of four-fifths of the water that had been applied six weeks previous.

ABSORPTION OF WATER IN EAST-SIDE FURROWS.

The observations on the eastern side of the orchard were not as full as those on the west. Borings were made near the upper end of the fourth line of furrows, and a trench was made in the lower end of the line to determine the limits of percolation and the amount of water held.

The soil of this part of the orchard is quite hard and compact beneath the mulch, especially at a few feet below the surface, making it a difficult matter to loosen it even with a pick. At 6 feet it is gritty and micaceous from the débris of the disintegration of the granitic hills on the south.

The percolation of the irrigation water in the upper end of the furrows was not to as great a depth as in the sandy loam soil of the western part of the orchard, but it reached to either side into the tree rows and seemed to wet the entire soil to a depth of 9 feet, as shown in the following table of percentages of water in each foot, before and after irrigation. The sudden falling off in percentages in the tenth foot of both tree and furrow rows indicates that the irrigation water reached a depth of only 9 feet instead of 26 or more feet as under the west-side furrows:

Water in the upper end of east-side furrows.

Depth.	Before irrigation.	Tree row.		Furrow row.	
		After irrigation.	Absorbed.	After irrigation.	Absorbed.
Feet.					
1	2.74	8.28	5.54	7.48	4.74
2	2.52	8.94	6.42	9.77	7.25
3	6.60	10.60	4.00	11.20	4.60
4	6.13	11.50	5.37	7.12	.99
5	4.05	11.14	7.09	10.52	6.47
6	3.24	11.63	8.39	7.72	4.48
7	2.21	10.11	7.90	5.73	3.52
8	5.10	10.52	5.42	10.36	5.26
9	4.41	11.55	7.14	11.30	6.89
10	....	4.56	....	3.17	....
11	....	3.82	....	6.88	....
12	....	2.37	....	3.42	....
13	....	6.56	....	3.24	....
Average	4.10	10.47	6.37	9.03	4.93

The hard, compact understratum evidently retarded the movement of the water downward and caused it to spread out to either side to the tree row, for we find 1.44 per cent more in the tree row than under the furrows.

A 1-foot section of the wet soil between the trees extending to a depth of 9 feet would doubtless show an average of 5.65 per cent of water (the mean of the two measurements) absorbed from the irrigation flow, which is equivalent to 134 gallons, or 1,119 pounds in a volume of 180 cubic feet. Here, again, we note the difference between this and the upper section on the west side, where the vertical wet area was 468 square feet and the water content of a 1-foot section 259 gallons, or 2,162 pounds, in a soil, however, that offered no resistance to the downward movement of the water.

Holes were bored in the middle section of the furrows and in the tree row on the same day as in the upper portion, and the amount of moisture ascertained. The table giving the results shows that the moisture through the ninth foot was largely in excess of the amount present before irrigation. Four feet below this, however, there was a large increase downward, but probably not from the irrigation supply above, the intermediate soil column being too uniform in its low-water content.

The percentages before irrigation given in the following table are from a few feet distant and are representative of conditions at these points. There is a large and sudden increase in the ninth foot, which doubtless continues downward as in the other columns.

Percentages of water in the middle portion of the east-side furrows.

Depth.	Before irrigation.	Fourth tree.		Fourth space.	
		Total.	Absorbed.	Total.	Absorbed.
Feet.					
1	3.58	2.48	−1.10	8.66	5.08
2	2.56	.36	−2.20	8.54	5.98
3	2.80	8.70	5.90	10.19	7.39
4	6.22	8.35	2.13	12.20	5.98
5	5.84	7.54	1.70	9.70	3.86
6	6.53	10.86	4.33	10.34	3.81
7	3.45	8.13	4.68	8.10	4.65
8	3.74	16.22	12.49	13.55	9.81
9	8.17	11.88	3.71	9.80	1.63
Averages.	4.77	8.28	3.52	10.12	5.35

In the tree row as shown above there was not only no surface absorption by seepage from the furrows, but the soil of the upper 2 feet was much drier than when the samples were taken some time before irrigation, the difference being due to evaporation; but in the third foot the absorbed water appeared, and thence down through the ninth foot was much in excess of that before irrigation, though not equal to that below the irrigation furrows.

The total amount of water in the depth of 9 feet was 8.28 per cent under the tree and 10.12 under the furrows. Deducting from these the 4.77 per cent present before irrigation, we find that 3.51 and 5.35 per cent was absorbed under the trees and furrows, respectively.

Lower end of furrows.—In the trench that was dug at the lower end of these eastern furrows we found that the extreme depth of percolation was 5 feet. The percentages of free water in the two wet sections between the trees under the four furrows are given in the diagram (fig. 4, p. 29), showing the percolation of the water.

The percentage of water found before irrigation, the average of total water found in each foot in depth of the entire 1-foot section after irrigation, and the amount absorbed from irrigation are given in the following table:

Percentages of water in lower end of east-side furrows.

Depth.	Before irrigation.	After irrigation.	Absorbed from irrigation.
Feet.			
1	4.94	10.94	6.00
2	4.14	10.83	6.69
3	5.60	9.33	3.73
4	6.50	8.83	3.33
5	3.28	8.63	5.35
Averages	4.89	9.91	5.02

In computing the general average under the column headed "after irrigation," the volume of wet soil for each foot in depth is taken into account and it is therefore higher than the simple average. The volume of the 1-foot section of wet soil for the four furrows was 34.4 cubic feet and it contained 5.02 per cent of water absorbed from irrigation, or the equivalent of 22.7 gallons (189 pounds).

OBSERVATIONS IN AN ORCHARD SHOWING THE EFFECT OF HARDPAN ON WATER MOVEMENTS.

We have seen in the eastern portion of orchard 58 the beneficial effects of a compact understratum when it underlies the soil at a depth of several feet, in that it prevents the accumulation of a large part of the water near the upper head ditch and causes it to be more evenly distributed along the furrows; there was, however, a large waste at the lower end. But when that hardpan is nearer the surface the effects are very different, as was observed in the movement of water in an orchard lying north of No. 80, where some very interesting data were obtained which have an important bearing on irrigation methods in the State. In the gritty clay loam that forms the soil the application of irrigation water, together with shallow plowing to the same depth year after year, has a tendency to wash the clay down into the subsoil to 1, 2, or 3 feet deep, and this being repeated year after year causes an accumulation of the clay not far below the surface. This clay, on drying, forms a kind of plow sole hardpan or "irrigation hardpan," as it is sometimes called, which is in some orchards very slowly penetrated by water. In other orchards the clay and grit become so firmly compacted as to resist completely the passage of water through the mass. These hardpans are wetted very slowly and much of the water flows over them to the lower part of the orchard. Some of these gritty clay beds, however, receive water and soften very readily, and it is only necessary to regulate the flow along the furrow accordingly.

The orchard mentioned illustrates very forcibly the effect of the presence of the compact impervious plow sole understratum, and the observations are given here to show the importance of an occasional deep breaking up of such compact subsoil, and the further importance of examinations while irrigation is in progress, to ascertain the movement of the water downward.

The orchard had been irrigated thirty days previous to this time and the trees were in good condition. The soil has a depth here of 12 to 15 feet or more and is made up of clay and granitic débris from the hills to the east.

The furrows for irrigation were from 3 to 5 inches in depth and four in number in the furrow space. An examination of the soil showed a hard compact stratum or hardpan at 5 inches below the mulch. This hardpan was from 6 to 10 inches thick, and beneath it the soil was quite moist. At 3 feet it was again compact and hard, while at 7 feet it was almost impenetrable to the auger. The result of the presence of the hardpan so near the surface was the rapid seepage of irrigation water to either side of the furrows and rapid wetting of the surface. Before irrigation water was turned on in this orchard the following percentages of water in the soil in the upper, middle, and lower parts of the furrows were found in depths to 7 and 8 feet:

Percentages of water in the soil before irrigation.

Depth.	Upper end.	Middle.	Lower end.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*
1	6.48	3.15	3.79
2	7.90	3.51	5.93
3	11.50	4.10	8.13
4	11.26	5.82	5.95
5	11.18	6.42	6.37
6	11.50	7.34	7.19
7	10.34		6.63
8	10.85		

The upper boring was made at about 100 feet from the head ditch where the trench was afterwards dug. The water percentage is quite high here and was evidently derived from the previous irrigation.

The middle boring was about midway of the length of the furrows, and the examination showed much less water than above, and even less than found in the boring 150 feet from the lower end of the furrow. The general averages of moisture in the soils of the several borings are in the depths reached, respectively, 10, 5, and 6.3 per cent, or in the upper 5 feet, 9.7, 4.6, and 6.1 per cent for the upper, middle, and lower, respectively.

Water was turned into the furrows by the irrigator on the morning of August 10, and thirty hours elapsed before it reached the lower end of the furrows, a distance of about 700 feet.

In the upper part of the furrows along the steeper slope the flow was about 10 feet in seven seconds, and after the water had run for twenty-four hours an examination showed that the water had penetrated but 5 inches below the bottom of the furrow to the hardpan and had spread 12 inches on either side of the furrow. At a point halfway down the furrows it was again observed that the water had spread sidewise into the mulch above the hardpan and very little downward into the latter. In this twenty-four hours it had wetted the greater part of the surface soil between the furrows. This rapid wetting of the surface is, of course, a source of great loss because of the evaporation that takes place.

At the end of twenty-four hours after irrigation had ceased, and the water had had sufficient time to soak as deeply as it could, examinations were made as to the extent of percolation and the amount of water absorbed from the irrigation. On orchard 58 it was shown that the water had penetrated from 4 feet to as much as 26 feet, but here the general average of percolation was only about 12 inches below the bottom of the furrow, even after four days.

The accompanying curves illustrate this graphically (figs. 5, 6, and 7). As usual the furrows had been made in pairs, the distance between the furrows in each pair being 3 feet and the distance between the pairs being about 5 feet. The wetted soil under the two furrows of each pair had united into one and formed some peculiar curves, as shown in the figures.

UPPER END OF FURROWS.

Near the head of the furrows 100 feet from the head ditch the depth of percolation downward was an average of but 10 inches below the bottom of the furrow. The slope is steeper than that of the lower half of the orchard, and the water passed rapidly through the furrows. This, together with resistance of the hardpan below, caused only a shallow downward wetting of the soil. The area wetted by percolation was scarcely increased over that observed when the water had run for twenty-three hours in the furrow, the increase being almost entirely in the upward surface wetting. The cross-sectional area under each furrow that was found to be wet at twenty-four hours after irrigation had ceased was but about 3 square feet, and the water held in the 1-foot section was 11.25 per cent, 6 per cent of which was present before irrigation, leaving but 5.25 per cent as the amount received from the flowing water. This means that only about 2.1 gallons were absorbed in the 1-foot section from the thousands of gallons that flowed through the four furrows at this point. In places the surface was wet for only a foot from the furrow, leaving wide, dry spaces between, while in others the entire surface from tree to tree was wet.

MIDDLE PART OF FURROWS.

The trench dug across the middle portion of the four furrows showed a shallow percolation and an extension of the wet surface entirely across from tree to tree, a distance of about 20 feet. The general depth of percolation was but 12 inches below the bottom of the furrows, except on the right, where in one place the water penetrated the hardpan and reached a depth of 2 feet in twenty-four hours after the water had been cut off. The depths of penetration are shown in the accompanying diagram (fig. 5) taken from the east face of the trench. The hardpan holds the moisture so tenaciously on its surface as to allow very little to penetrate it, thus compelling the greater part of the flow to pass on toward the lower part of the orchard.

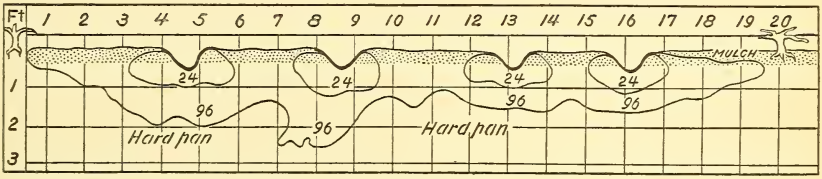

FIG. 5.—Outlines of percolation twenty-four hours after irrigation ceased, where hardpan is near the surface, near middle of furrows.

The vertical area wetted by the irrigation water was about 24 square feet in the section. A 1-foot section held the following averages of water before and after irrigation, in 24 cubic feet:

Percentages of water in the middle of the furrows.

Depth.	Before irrigation.	After irrigation.	Absorbed from irrigation.
Mulch	0.5	14.5	14.0
First foot	3.2	13.5	10.3
Second foot (one place)	3.5	12.1	8.6

Calculating the total average of that absorbed, according to the space wetted in each foot of depth, we find that 10.3 per cent of water was taken from the irrigation water as it passed over the section. This is equivalent to 32.5 gallons or 271 pounds.

LOWER END OF FURROWS.

It will be seen from the diagram (fig. 6) that in the lower portion of the furrows at 120 feet from the end the water had soaked to a maximum depth of only 18 inches in the three days' irrigation, and that between the furrows the line marking the lower limit curves upward into the mulch. The entire vertical wet area in the cross section of the four furrows was about 13 square feet. The amount of water absorbed and held by the soil below the four rows was 13.26 per cent; deducting the amount of water present before irrigation we find a general average of 9.47 per cent that was absorbed from the irrigation water. This is equivalent to 16.2 gallons (135 pounds) of water in the section of 13 cubic feet.

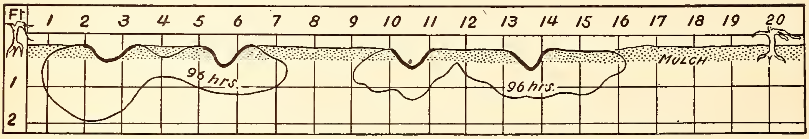

FIG. 6.—Outlines of percolation, twenty-four hours after irrigation ceased, where hardpan is near the surface, near lower end of furrows.

At the immediate foot of the furrows, 15 feet from the ditch where the water was allowed to accumulate in cross furrows, the percolation downward was about as in the middle section, reaching a depth of only 8 inches below the bottom of the furrows, but the surface mulch was wet entirely across the furrows from tree to tree. Figure 7 illustrates the depths of percolation under two of these furrows. A 1-foot section of the furrows gives about 6 cubic feet for the two. The mulch comprises the chief part of that which was wet, and held 16.7 per cent of water absorbed from irrigation.

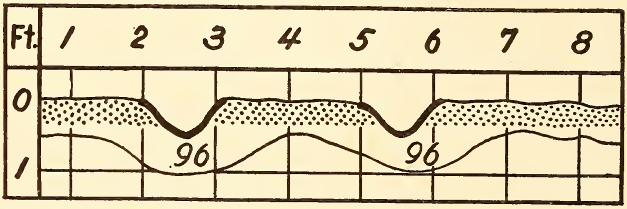

FIG. 7.—Outlines of percolation where hardpan is near the surface, 15 feet from lower end of furrows.

The hardpan below contained but 1.7 per cent of absorbed water. The total for the two furrows was about 6.5 gallons, or 53 pounds. Nearer the end, or 5 feet from it, the surface mulch held about 14 per cent of absorbed water and the percolation was more limited than in that above. Here we have a very strong contrast with the depth of percolation in loose sandy loams of orchard No. 58; there the excess was absorbed in 14 feet, while here the hardpan prevented percolation and caused the great excess to flow off into the adjoining orchard.

AMOUNT OF IRRIGATION WATER ABSORBED.

It is of course impossible to ascertain the exact amount of water absorbed by the soil, but, as in other orchards, we may make an approximation based on that held in the several sections, namely, 10 gallons in the steep slope at 100 feet from the head ditch, 32.5 gallons at 380 feet from the ditch, and 16.2 gallons at 580 feet from the upper or 120 feet from the lower end of the furrows. This would give about 15,000 gallons, or a little more than 125,000 pounds, as the amount absorbed.

All of this was, however, held in the upper foot of soil by the underlying hardpan, and doubtless was all lost by evaporation into the air before five days had elapsed. It is thus clearly indicated that under the above conditions the trees received almost no benefit from the application of irrigation water.

EFFECT OF HARDPAN.

The above examinations show plainly that when an impermeable plowsole is allowed to remain near the surface it produces serious results: (1) By the failure to absorb the greater part of the water, thus permitting it to flow to the lower part of the orchard and out into the adjoining lands; (2) by facilitating sidewise surface seepage from the furrows and exposing a greater area to evaporation by the heat of the sun; (3) by holding the water near the surface and thus causing its loss by evaporation before the soil is cultivated; (4) by preventing access of the water to the roots of the trees lying below the hardpan; (5) by preventing proper ventilation and aeration of the subsoil.

OBSERVATIONS OF WATER MOVEMENTS IN ORCHARD NO. 80.

Having concluded, as far as practicable, the experiments on Block 58, it was decided to conduct further observations on soils of a different type than the sandy loam, although it was realized that comparatively recent irrigation would interfere somewhat with the results and the conclusions drawn from them. It was thought best, also, to restrict the choice to the orchards of a single company, because of uniformity of methods of irrigation. This orchard was chosen because the soil was considered typical of the land along the Gage Canal from High Grove on the north to Rumsey's orchard on the south. It lies near the foothills and slopes to the west. The trees are 22 feet apart, but their arrangement is different from that in No. 58, in that they are not at right angles with the head ditch.

The soil is a heavy loam, its weight per cubic foot being 105 pounds. The trees were large and dark green in color, and in excellent condition. They had thrown out fresh shoots, thus showing the presence of abundant water. A series of four furrows, comprising a space between two rows of trees, was selected, as no extended examination could be undertaken as was done in No. 58.

PRELIMINARY EXAMINATION.

Trenches were made across the furrows near the head ditch, half way down, and near the lower end of the furrows; samples of soil were carefully taken from several columns in the upper face of each trench, and the amount of free moisture determined. The results are given in the following table:

Percentages of water in the soil before irrigation.

Depth.	Upper trench.				Middle trench.			Lower trench.		
	No. 1.	No. 2.	No. 3.	Average.	No. 1.	No. 2.	Average.	No. 1.	No. 2.	Average.
Feet.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	3.05	3.34	3.33	3.24	4.42	2.18	3.30	2.29	2.42	2.36
2	4.06	3.61	6.49	4.72	2.95	3.74	3.34	2.59	2.48	2.53
3	5.02	7.05	6.93	6.33	5.88	4.50	5.19	3.46	3.03	3.24
4	6.30	8.09	10.27	8.22	9.05	7.43	8.24	6.54	3.20	4.87
5	10.02	9.40	9.89	9.77	9.38	8.55	6.86	6.37	4.60	5.48
6	8.82	8.72	10.28	9.27		8.04		7.67	5.48	6.57
7	6.87	8.48	6.54	7.29		11.83			5.01	
8	7.09	5.44	7.12	6.55		10.60			3.60	
9	10.10	8.47	8.59	12.76						
10	12.80	6.45	11.68	10.31						
11	13.50	11.42	4.69	9.87						
12		14.23	15.65	14.99						
13		15.47	14.56	15.01						
Average	7.97	8.47	8.92	9.10	6.33	7.11	5.38	4.82	3.73	4.18
5 feet	5.69	6.30	7.38	6.45	6.33	5.28	5.38	4.25	3.15	3.70

In comparing the water content of the upper, middle, and lower parts of the furrows we find that the upper contained the most water and the lower the least amount, the average percentages for 5-foot depths being, respectively, 6.45, 5.38, and 3.70, thus showing that the effects of the former irrigation were still felt by the soil and that the largest part of that irrigation was received in the upper ends of the furrows, the other portions following consecutively from highest to lowest.

It is also noted that the water had accumulated in the lower depths of the several columns with percentages more than double those nearer the surface, there being as much as 15 per cent in the twelfth foot. There had been two irrigations previous to this, the last being 20 inches per day for three days beginning June 26, or forty days before the time of this application. The water, therefore, had had ample time to move down through several feet.

APPLICATION OF WATER.

The four furrows occupying the space between the rows of trees were made with the usual shovel marker and were 4 inches deep. The soil was covered with a mulch usually 6 inches deep in the furrow space and 4 to 5 inches in the tree row. The upper trench was 110 feet from the ditch, the second or middle trench 240 feet from the first, and the third or lower one was 240 feet from the second and 110 feet from the lower end of the furrows.

Water was turned on at the weir on August 8 and was allowed to run for seventy-six hours with a volume of 48 miner's inches. In one of the furrows it reached the upper trench, a distance of 110 feet, in five minutes, in other furrows in eleven and forty-eight minutes, respectively.

VOLUME OF WATER FROM HEAD DITCH INTO THE FURROWS.

Measurements of the flow from two orifices in the head ditch were made during irrigation to ascertain the amount delivered to each furrow, and further measurements were made at each of the trenches.

Rate of flow of irrigation water in Orchard No. 80.

Position.	West furrow.		East furrow.	
	Time.	Flow.	Time.	Flow.
	a. m.	*Gallons per minute.*	*a. m.*	*Gallons per minute.*
At ditch	9.00	1.307	9.30	1.973
First trench	9.45	.938	10.00	1.587
Third trench	10.30	.250	11.00	.330

There was, therefore, a disappearance of 81 per cent of water in the westerly furrow and 83.3 per cent in the easterly between the head ditch and the lower end. This means an average of 82.2 per cent of the water, in part evaporated from the surface into the air and in part received by the soil to within 110 feet of the lower end. For the entire space of four furrows we therefore obtain the following summary for the seventy-six hours' flow:

Flow from the head ditch, 76 hours, 29,914 gallons.
Received at the upper trench, 76 hours, 23,019 gallons.
Received at the lower trench, 54 hours, 3,758 gallons.

Between the ditch and the first trench, a distance of 110 feet, there disappeared 6,895 gallons, or about 23 per cent of the whole; while between the upper and lower trenches, a distance of 440 feet, 19,261 gallons disappeared, or about 64 per cent of the whole, leaving the remaining 3,758 gallons to be received by the lower part of the furrows, 110 feet in length, at the extreme end of which cross furrows had been made to receive the excess and over which the water spread and finally disappeared.

TEMPERATURE OF THE WATER.

The amount of heat absorbed by the water as it passed from the head ditch to the end of the furrows is shown in the following table, which gives the temperature of the water at the three points of measurement:

Changes in temperature of water in the furrow.

Time.	Location.	West furrow.	East furrow.
a. m.		°*F.*	°*F.*
8.30	Upper trench	72.0	67.5
8.30	Middle trench	74.0	68.5
8.30	Lower trench	74.0	71.0
9.45	Upper trench	75.5	....
10.00	.....do	....	78.0
10.30	Lower trench	91.0	....
11.00	.....do	....	84.0

At the upper trench there was an increase of 3.5° in the west furrow in seventy-five minutes and 10.5° in the east furrow in ninety minutes. At the lower trench the water of the west furrow increased in temperature 17° in two hours, while that of the east furrow increased 13° in two and five-tenths hours. The east furrow was more under the shade of the trees than the other, which perhaps accounts for the difference.

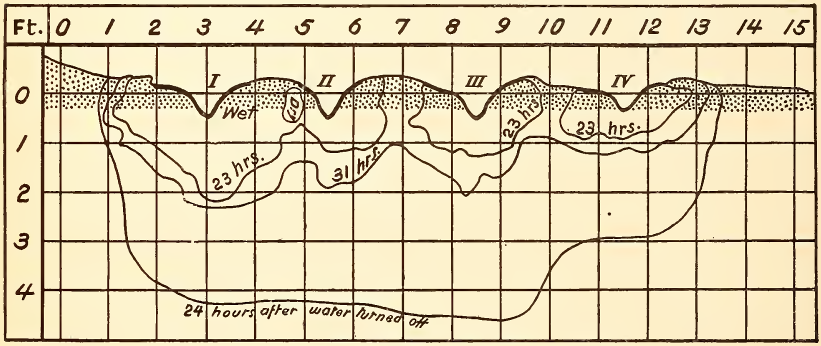

FIG. 8.—Outlines of percolation at upper trench in orchard 58.

PERCOLATION AND ABSORPTION OF WATER.

The depth penetrated by irrigation water was much less than on Block 58, as shown by the accompanying diagrams. This may have been due to the more compact condition of the beds beneath the mulch.

AT THE UPPER TRENCH.

Here the water had reached a depth of 1.5 feet below the bottom of the furrow at the end of twenty-three hours, and in eight more hours had passed down but 6 inches farther. (See fig. 8.) The furrows I and II are quite near together, 2.5 feet, and the water from these quickly united to form a continuous curve with a wet section 7.5 square feet. Furrows III and IV were a little farther apart, and for twenty-three hours the wet area of each remained distinct, the former with but 2.25 square feet and the latter 1.75 square feet. At the end of thirty-one hours the wet sections of all had united, forming a very irregular outline, having the usual deeper extension below each furrow and comprising a total vertical section of about 18 square feet. The entire depth of penetration twenty-four hours after irrigation ceased was 4.5 feet beneath the bottom of the furrows and the wet area about 42 square feet. The several horizontal layers contained the following percentages of free water:

Percentages of water in upper section.

Depth.	Wet area.	Total water.	Before irrigation.	Absorbed.
Feet.	*Square feet.*	*Per cent.*	*Per cent.*	*Per cent.*
½	5	9.42	3.24	6.18
1	13	8.84	4.72	4.12
2	12	8.93	6.33	2.60
3	10	9.13	8.22	.91
4	2	9.93	9.77	.16

These results give a percentage of 2.98 as that absorbed from irrigation water, which is equivalent to 15.7 gallons (131 pounds) in a 1-foot section for the four furrows held in the soil twenty-four hours after water was cut off.

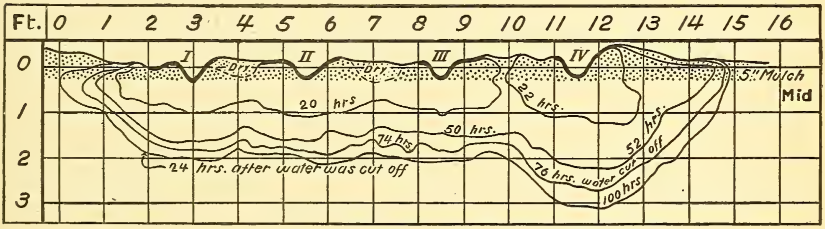

FIG. 9.—Outlines of percolation at middle trench in orchard 80.

AT THE MIDDLE TRENCH.

At the middle trench the furrows were also within 2.5 feet of each other and the water quickly spread to either side (see fig. 9) because of the hard, compact nature of the earth, and formed a continuous wet face on the east side of the trench. It reached as much as 3 feet beyond the extreme furrows and to an almost uniform depth of 2 feet beneath the bottom of the furrows, except under the south furrow, where it penetrated to a little more than 3 feet, because of the softer nature of the soil.

In twenty hours after the water had reached the place the penetration was but 1 foot, with a vertical wet area of 10.25 square feet. When water was cut off at the end of seventy-four hours the vertical wet area was 23 square feet, and in the next twenty-four hours it had expanded to 30 square feet. An examination gave the following percentages of water.

Percentages of water in the middle section.

Depth.	Wet area.	Total water.	Before irrigation.	Absorbed.
Feet.	*Square feet.*	*Per cent.*	*Per cent.*	*Per cent.*
½	6	12.78	3.30	9.48
1	14	11.20	3.35	7.85
2	8	10.38	5.19	5.19
3	2	9.76	8.24	1.52

In these columns the wet mulch between the furrows contained an average of nearly 13 per cent of water. Beneath the mulch the amount diminished to the bottom, and as seen in the table the third foot contained but 1.52 per cent more than was originally in the soil. The general average percentage of water absorbed from the irrigation flow was 7.12, or 26.8 gallons (224 pounds) in the 1-foot section.

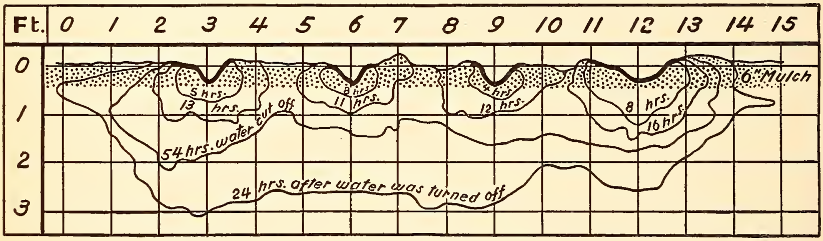

FIG. 10.—Outlines of percolation at lower trench in orchard 80.

In the middle section we miss the usual final irregular curves, which in most of the other localities reached to a greater depth immediately below the furrows, though there is seen a slight tendency to this in some of the lines. We do, however, have the inward curving along the sides of the wet space.

AT THE LOWER TRENCH.

In the lower trench we find conditions even worse than above, for, as seen in the diagram (fig. 10), water has penetrated to a depth of but about 2.5 feet beneath the bottom of the furrows, except under one furrow, and under each furrow the curves were independent of each other near the time the water was cut off.

Had the soil been less compact and hard the penetration would have been greater, for the amount of water passing over the locality was about 3,728 gallons for the four furrows. The area wetted, as shown by the vertical cross section, was about 34 square feet. An examination gave the following percentages of water in a 1-foot section:

Percentages of water in the lower section.

Depth	Wet area.	Total water.	Before irrigation.	Absorbed.
Feet.	*Square feet.*	*Per cent.*	*Per cent.*	*Per cent.*
½	6	11.27	2.36	8.91
1	14	8.65	2.53	6.12
2	14	6.97	3.24	3.73

The amount of water absorbed from irrigation was 5.63 per cent, or about 24 gallons in the 1-foot section. At the end of the furrows the excess of water penetrated to a depth of but 8 feet.

From the above tables and the distances between the trenches we may, as in other orchards, obtain an approximation of the amount held by the soil of the four furrows at the time of examination. This would be about 16,000 gallons. For a distance of 60 feet or more from the head ditch, however, the water percolated to a depth of 8 feet, as shown in later borings, and held 4.30 per cent of water in the upper 5 feet and 3.73 per cent in the whole column, thus adding fully 2,000 gallons to the estimate.

WATER IN THE SOIL FIVE DAYS AFTER IRRIGATION.

When cultivation of the orchard was begun after irrigation, borings were made along the line of furrows across which the trenches were previously made.

The upper boring was made midway between the head ditch and the upper trench, the hole being bored to a depth of 16 feet. The second hole was bored midway between the upper and middle trenches. It penetrated to a depth of 13 feet. The material at 6 feet was gritty, hard, and compact. At 12 feet the auger entered the soil with difficulty. The third hole was made midway between the middle and lower trenches, the auger penetrating but 8 feet, where the soil again was found to be hard and compact. The last hole was bored near the lower trench only to a depth of 5 feet, where the soil suddenly became hard and very dry.

The results of the moisture determination in each place are shown in the following table:

Total percentages of free water five days after irrigation, orchard 80.

Depth.	Upper hole.	Second hole.	Third hole.	Lower hole.
Feet.				
1	7.60	7.60	10.02	9.75
2	7.68	7.88	7.72	7.84
3	11.37	7.04	9.73	9.57
4	12.58	7.62	7.85	10.45
5	14.50	9.53	6.14	4.07
6	10.91	8.49	8.37	....
7	13.30	5.88	6.15	....
8	8.08	11.18	8.60	....
9	6.58	10.30	....	....
10	12.41	11.32	....	....
11	16.95	8.69	....	....
12	15.57	9.12	....	....
13	11.76	9.87	....	....
14	9.60	....	....	....
15	7.61	....	....	....
16	8.88	....	....	....

These holes were dug at points as near the irrigating furrows as possible, as there the water would be at its maximum. The upper boring shows very large percentages of water still left from the irrigation, while in other places there is a very material falling off from the results obtained previously.

PERCOLATION FROM SHALLOW AND FROM DEEP FURROWS.

An experiment was made on a small scale on the soil of orchard 58 by allowing a small stream of water to flow through furrows having depths of 10 and 5 inches, respectively, for several hours. The results are shown in figures 11 and 12. It will be seen that while in the shallow furrow the water rose to the surface on either side it failed to do so from the deep furrow. Moreover, in this sandy loam soil the depth of percolation and the spread of the water were far greater under the deep furrow, the ratio being 2 to 1.

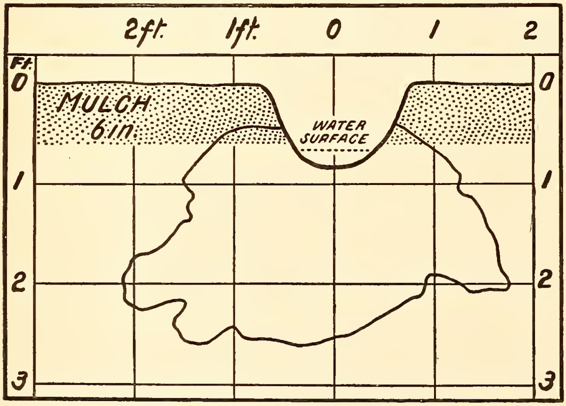

Fig. 11.—Outlines of percolation from furrow 10 inches deep, in seven hours.

In orchard No. 80, where the soil was more compact, the movement downward was quite slow and two furrows having a depth of 8 inches were made to ascertain whether there would be any advantages above the ordinary depth of 5 or 6 inches. The deep furrows loosened up the compact soil to a greater depth, but the downward percolation was no greater than beneath the shallow furrows, as will be seen on comparing figure 13 with figure 9. The accompanying diagram (fig. 13) shows the curves produced at successive periods by the movement of the water downward. On either side of each of these furrows the wet portion of the mulch contained an average of nearly 10 per cent of free water, as did the soil also to a depth of 1 foot below the furrow, but the wet portion of the mulch was narrow at the surface and widened downward for a short distance, leaving dry soil above it. The diagram also shows that the wet sections beneath the two deep furrows failed to unite on the surface as they do under the shallow ones of figures 14 and 15 (pp. 48 and 49), although the furrows were only 4 feet apart. They still remained apart twenty-four hours after the water was turned off, although the conditions for sidewise seepage were more favorable than in sandy loam soils.

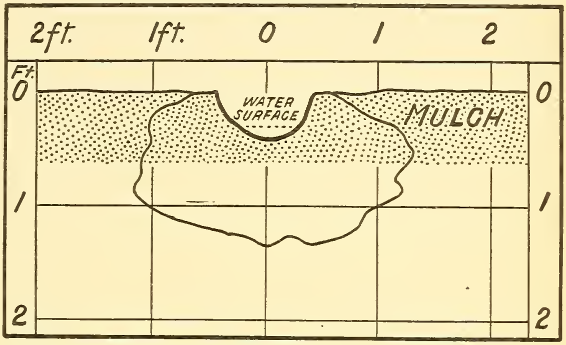

Fig. 12.—Outlines of percolation from furrow 5 inches deep, in seven hours.

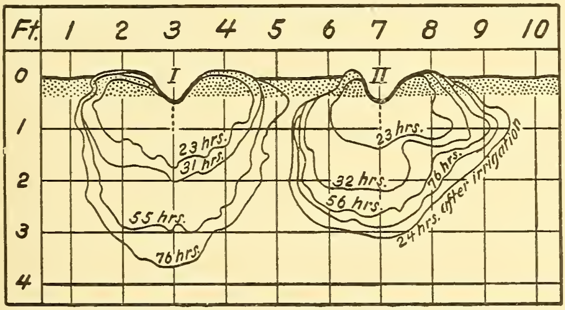

Fig. 13.—Outlines of percolation in compact soil from furrows 8 inches deep.

In the following table is given the area of the wetted portion in a vertical section of each furrow, the total percentage of water held twenty-four hours after irrigation, and the amount absorbed from irrigation over and above that present before in a 1-foot section. The equivalent amounts in gallons are also given:

Percolation of water under two deep furrows.

Furrow.	Area.	Total water.		Absorbed.	
	Square feet.	*Per cent.*	*Gallons.*	*Per cent.*	*Gallons.*
1.......	10.5	9.4	12.4	6.0	8.0
2.......	8.5	8.5	9.1	6.9	7.3
	19.0	9.0	21.5	6.4	15.3

The wet area of furrow No. 1 is very regular in its outlines, while that of No. 2 extends out to the right in such a manner as to indicate the presence of an usually compact soil at that point.

The soil was very gritty and compact and in the first twenty-three hours, while the movement of water was very slow, the area under No. 1 was 4.25 square feet and under No. 2 but 2.25 square feet. In the succeeding periods, however, the areas were about the same.

As seen in the table, the combined wet section was 19 square feet and the amount of total free water 9 per cent, or 21.5 gallons. Deducting from this the amount in the soil before water was applied, there is left 6.4 per cent, or 15.3 gallons as that received from the irrigation and held at the time the samples were taken. A comparison of these with two of the shallow furrows of this middle section (fig. 9, p. 41) is given in the following table:

Kind of furrow.	Wet area.	Water absorbed.
	Sq. feet.	*Gallons.*
Deep furrows	19	15.3
Shallow furrows	15	13.4
Difference	4	1.9

The differences do not seem great, but if maintained throughout the four furrows indicate an increase of about 2,500 gallons in favor of the deep ones from one end to the other.

The real advantage in deep furrows lies in increasing the height of soil through which the water from the furrows would have to rise by capillarity to reach the surface, thus decreasing evaporation and increasing the amount of water retained by the soil. When we remember that the greatest, and oftentimes the only, loss of irrigation water is by evaporation, the value of deep furrows is apparent.

OBSERVATIONS IN THE MYLNE ORCHARD.

The orchard belonging to Mr. J. M. Mylne lies on the block west of No. 58, and has a gritty clay loam soil, with a subsoil which, when dry, is very compact and hard to break up, even with a pick. It, however, quickly absorbs water and becomes soft. It is composed of a reddish clay mixed with the grit and sand débris from the disintegration of the granite rocks of the mountains on the south.

A chemical examination of the soil shows an almost entire absence of humus and indicates the great need of growing and turning under a good green-manure crop. If this is done, and the green material is properly covered by the soil and allowed to humify, it will greatly aid in loosening up the soil, producing better aeration, less compacting, and a higher moisture capacity, and at the same time it will enrich the soil with plant food. The soil received but a shallow tillage, the mulch having a thickness of but 3 or 4 inches. When compacted, it is a very refractory hardpan, not penetrated by the auger if dry, but it softens rather easily when water is applied. Hardpan occurs in several layers; one at 6 inches and another at 18 inches below the surface; and again at 6 feet with a thickness of a foot. The trees were 22 feet apart and were of medium thriftiness.

Three trenches were dug across the five irrigation furrows, to the depth of 5 feet, and then borings were made to 10 feet. The upper and lower trenches were, respectively, 3 and 5 feet from the ends and the middle trench at 330 feet from the end. From the surface down to 7 feet the material was dry, but below that depth was very wet, perhaps from seepage from orchards farther up the hill. The orchard had been irrigated six weeks previous to this, but the water had nearly all disappeared from the upper 3 feet, though present in large amount below that depth.

As preliminary to the irrigation, to ascertain the amount of water in the soil remaining from the last irrigation, samples were taken from two columns in each of the trenches, and the percentages of moisture determined. The results as given in the table below show that there was enough water in the upper 4 feet in each part of the furrows to maintain vitality, but not to produce new growth. Then there was a sudden increase of 4 per cent in the fifth foot of each trench, due perhaps, to the previous irrigation.

Percentages of water in the soil before irrigation.

Depth.	Upper trench.	Middle trench.	Lower trench.	Average.
Feet.				
1	6.30	3.28	3.97	4.52
2	7.06	4.97	7.02	6.35
3	6.81	9.33	5.92	7.35
4	11.19	9.13	7.42	9.24
5	12.90	7.04	11.78	10.57
6	9.34	11.30	12.10	11.24
7	8.91	12.90	10.39	10.73
8	11.89	13.20	7.82	10.97
9	6.40	....	7.28	6.84
10	2.85	....	5.52	4.18
Average	18.37	8.90	7.92	8.20

Water was turned into the furrows on July 19, and allowed to flow for three days. It flowed over the upper trench sixty-six hours, over the middle fifty-four hours, and over the lower forty hours. These figures also indicate the time required to reach each trench from the head ditch—six hours to reach the upper trench through a distance of about 125 feet; eighteen hours to reach the middle, and thirty-two hours to reach the lower trench. To this slow movement is due chiefly a large evaporation of moisture from the surface during the hot days that then prevailed. Mr. Roadhouse found the temperature of the wet soil at 2 p. m. to be 94°, while that of the air was 90°.

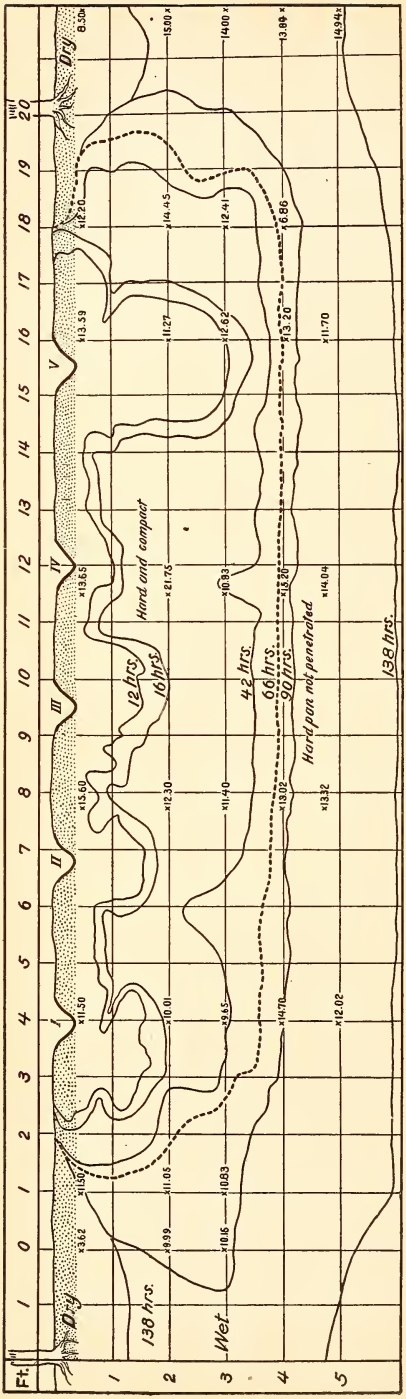

FIG. 14.—Outlines of percolation in Mylne orchard, upper trench.

PERCOLATION OF THE WATER.

In the flow of the water down the furrows across the upper trench, the hard compact soil resisted the downward percolation to such an extent that at the end of twelve hours the line marking the limit presented a remarkably irregular outline; the depth of the wet soil was only about 12 inches immediately below the bottom of the furrow, while on either side it had barely passed below the mulch. Under one of the furrows the water seemed to have followed some roots and found its way to the depth of 2.5 feet. The mulch of about 4 inches was quickly wetted across the furrows from tree to tree. The progress of the movement is shown by the accompanying diagram (fig. 14).

At the end of forty-two hours the downward movement had become more regular through the compact, gritty mass and had reached a depth of 2.5 to 3.5 feet below the bottom of the furrow. This was increased 6 inches at the end of sixty-six hours, when the water was cut off at the head ditch. After this there was scarcely any movement of the water.

The wet vertical area shown on the face of the upper trench covered 72 square feet. It was longer at the surface than below, thus showing somewhat the inward curve as noticed in other orchards. The lateral movement was about 2.5 feet beyond the furrow on one side of the wet area and 5 feet on the other, because of the presence of large roots which the water followed through the hard mass.

In the middle trench the movement of the water showed the same irregularities, until just before the time when the water was cut off. (See fig. 15.) Under one furrow the earth was soft and the water penetrated 2.5 feet beneath the bottom of the furrow in twelve hours; while under the others the gritty mass was compact and hard, and the penetration varied from 6 to 12 inches, and hardly below the wet mulch between the furrows. At the end of thirty hours the water had gone but 6 to 12 inches deeper, and at the end of fifty-four hours, when the water was cut off, it was at a depth of 2 feet beneath the

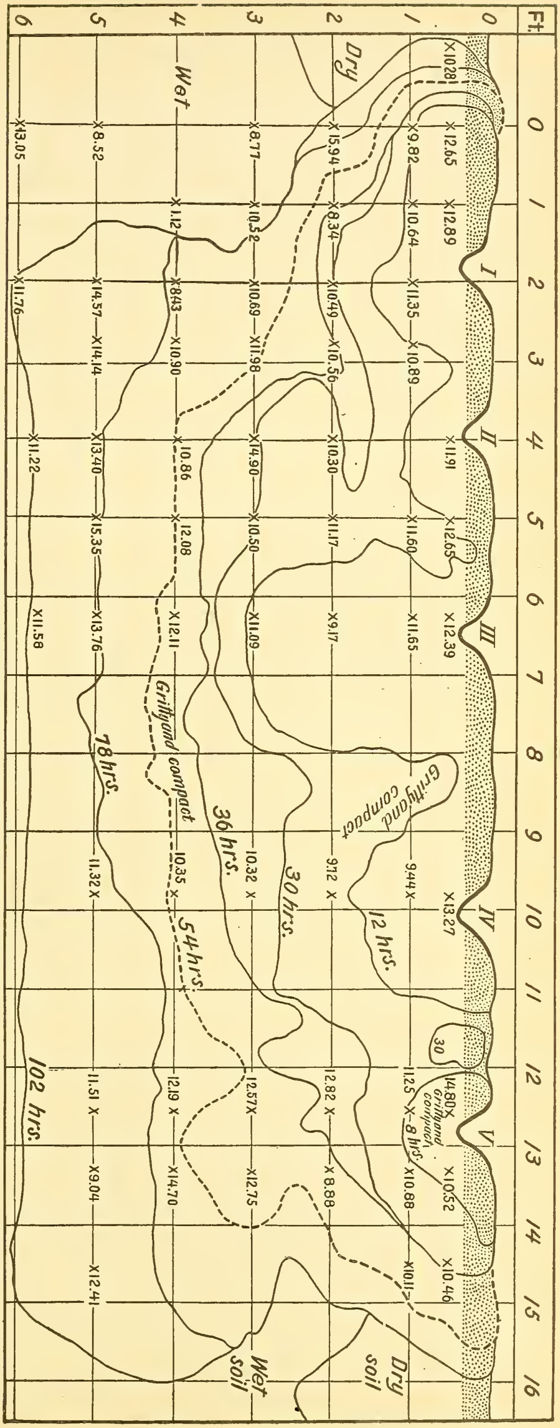

Fig. 15.—Outlines of percolation in Mylne Orchard, middle trench.

side furrows and nearly 4 feet in the middle, where the soil was softer.

A close compact condition greatly retarded the downward movement of the water. The vertical area wetted at the end of seventy-eight hours, as shown on the face of the middle trench, was 60 square feet or 12.5 feet less than in the upper trench. The extreme length of the wet area was about 16 feet. On one side the line marking the limit curves toward the middle, while on the other it was more nearly vertical.

The lower part of these furrows received water for a less time and the rate of percolation was more regular (fig. 16). Under three of the furrows the water quickly united and the depth reached in sixteen hours was from 12 to 24 inches beneath the bottom of the furrow. Under the other two furrows the percolating waters reached a depth of about 12 inches in the hard compact soil at the end of sixteen hours, and did not unite until forty hours had elapsed.

The length of the wet area shown in the face of the trench was 17 feet at the surface and a little

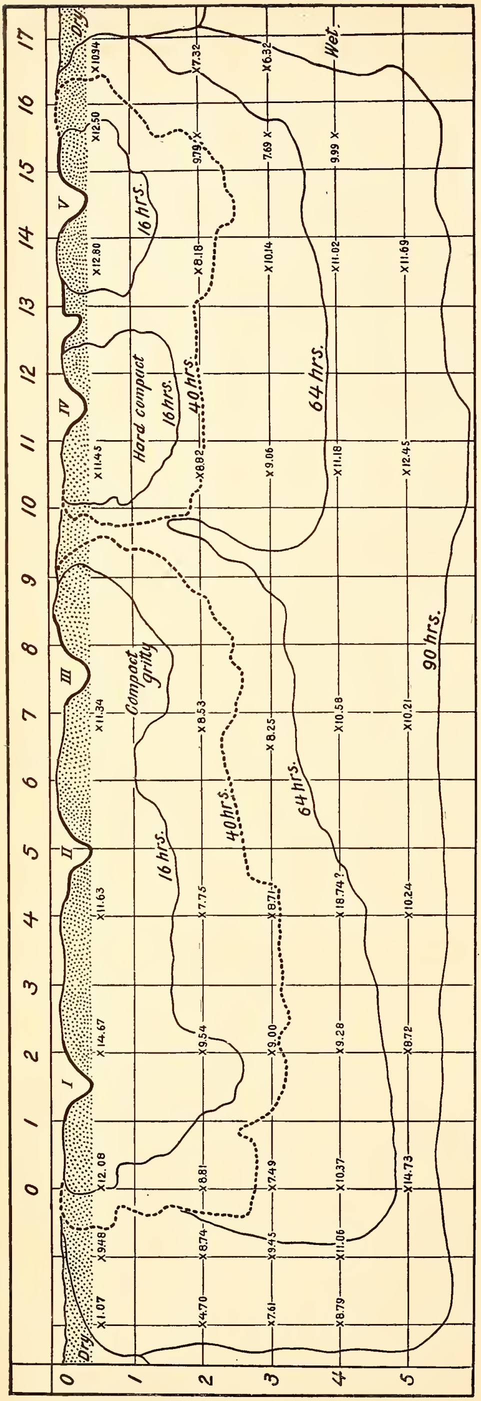

FIG. 16.—Outlines of percolation in Mylne orchard, lower trench.

less at the bottom. The depth was 4.5 to 3.5 feet, and the total area was 56 square feet, or a little less than at the middle.

The vertical section that was wetted by the percolating water was naturally greater near the head ditch than elsewhere, the difference between the upper and lower trenches being 16 square feet. The percolation was therefore more uniform in this orchard than in any other experimented with, this being due to the compact nature of the soil and the consequent very slow downward movement of the water.

PROGRESS OF PERCOLATION.

It is interesting to observe the progress of the water downward in the soil and its movements in different directions. The outlines of these were carefully observed and marked at each time, and the results are shown in the following table:

Increase in depth and area during successive periods.

Upper.			Middle.			Lower.		
Time.	Depth.	Area.	Time.	Depth.	Area.	Time.	Depth.	Area.
Hours.	*Inches.*	*Sq. ft.*	*Hours.*	*Inches.*	*Sq. ft.*	*Hours.*	*Inches.*	*Sq. ft.*
12	12–30	18	12	6–30	15	16	12–26	17
12–42	12–24	36	12–36	6–12	20	12–40[a]	6–12	16
42–66[a]	3–6	9	36–54[a]	6–18	11	40–64	12–20	23
66–90	3–6	9	54–78	6–18	14	....	....	....
90	51	72	78	60	60	64	53	56

[a] Irrigation water cut-off.

The extreme depth of penetration was greatest in the middle and least in the upper section, though the area wetted was greatest in the upper and least in the lower section.

The increase in wet areas seems to have progressed uniformly during the first forty-two hours in the upper part of the furrows and at the rate of 1.5 and 1.2 square feet per hour, but fell to a little over $\frac{1}{3}$ square foot at the end.

In the lower part the rate was 1 foot per hour at first, 0.67 foot for the next twenty-four hours, and an increase at the last to nearly a foot per hour.

LOSS OF WATER BY EVAPORATION.

The loss by evaporation from the flowing water in the furrows during the hot days of July was considerable, for it was observed that each day at 10 a. m. the water evaporated so rapidly as to cause the front of the flow to recede up the furrow for 125 feet. The evaporation from the wet surface was fully as great, for it rapidly dried out. Mr. Roadhouse observed that twenty-four hours after irrigation had ceased the soil was dry enough to walk upon.

AMOUNT OF IRRIGATION WATER ABSORBED.

The amount of irrigation water absorbed was ascertained in the 1-foot sections underneath the furrows at each trench, the number of cubic feet of wet soil being 72, 60, and 56 for the upper, middle, and lower trenches, respectively. The weight of the compact soil of this orchard was 105 pounds per cubic foot. The percentages of irrigation water absorbed in the depth of percolation were as shown in the following table:

Percentages of water held by the soil.

Depth.	Upper.		Middle.		Lower.	
	Total held.	From irrigation.	Total held.	From irrigation.	Total held.	From irrigation.
Inches.						
12	11.96	5.66	11.47	8.19	11.98	8.01
24	15.61	8.55	10.75	5.78	8.31	1.29
36	12.56	5.75	11.29	1.90	7.37	1.45
48	12.27	1.08	10.30	1.11	11.22	3.80
60	....	....	12.40	5.36	....	....
Averages.	13.10	5.26	11.24	4.49	9.47	3.64

From these data we find that the 1-foot sections at the several trenches held the following amounts of water:

Water held in a 1-foot section across the furrows at each trench.

	Area.	Total held.		Absorbed from irrigation.		
	Cu. ft.	*Per cent.*	*Gallons.*	*Per cent.*	*Pounds.*	*Gallons.*
Upper trench	72	13.10	117.4	5.26	397	47.62
Middle trench	60	11.24	84.8	4.49	283	33.87
Lower trench	56	9.47	60.7	3.64	215	25.70

The upper part of the furrows held the larger part of the water given by irrigation, and distributed it through a greater vertical area. Basing a calculation on the above table and the respective distances between the trenches, we estimate that about 23,000 gallons were absorbed from the irrigation water by the four furrows.

AMOUNT PRESENT ONE MONTH LATER.

One month after this, samples of the soil from near the upper and lower trenches were obtained by borings, and the amount of water remaining at that time was ascertained. The percentage in each foot is shown in the following table, together with the average results obtained before and immediately after irrigation.

Percentages of water in soil one month after irrigation.

Depth.	Upper end of furrows.			Lower end of furrows.		
	Before irrigation.	Immediately after.	One month later.	Before irrigation.	Immediately after.	One month later.
Feet.						
1.....	6.30	11.96	7.92	3.97	11.98	7.34
2.....	7.06	15.61	9.25	7.02	8.31	8.22
3.....	6.81	12.56	7.62	5.92	7.37	7.39
4.....	11.19	12.27	13.02	7.42	11.22	7.49
5.....	12.90	12.90	12.35	11.78	11.78	11.13
6.....	9.34	9.34	11.23	12.10	12.10	11.06
7.....	8.91	8.91	11.39	10.39	10.39	10.86
8.....	11.89	11.89	7.62	7.82	7.82	12.69
9.....	6.40	6.40	2.87	7.28	7.28	8.17
	8.98	11.32	9.25	8.19	9.81	9.15

The water received from irrigation increased the percentage in the upper 4 feet by 5.26 per cent near the head and 3.64 per cent near the foot of the furrows. These amounts distributed through a depth of 9 feet would give respective increases of 2.34 and 1.61 per cent, as shown in the above table. The examination of the soil near the upper and lower trenches one month after irrigation showed a loss of 2.07 per cent in the upper and 0.66 per cent in the lower end in a depth of 9 feet. In the upper the amount was reduced to but little more than was present before irrigation, while in the lower end it was almost 1 per cent more.

It seems, then, that the water of the upper 4 feet of the soil of the two ends of the furrows was but 0.62 per cent more than previous to irrigation and thus had in one month, by evaporation, by absorption by tree roots, and probably by slight downward movement, almost returned to its normal amount before irrigation

OBSERVATIONS IN OTHER GROVES.

While the work in the above orchards was in progress, some observations were made in others with the hope that the results would add something of value gathered from the various methods of cultivation practiced on each. Irrigation water had already been applied, and we could only note the disposition of the water at various times. Some of the results are of interest.

THE BEULAH GROVE.

The Beulah grove is immediately adjoining the Mylne grove on the east and has the same character of soil common to the orchards of this portion of the Arlington Heights lands. The first foot is a hard, compact loam with some grit; the next 4 feet a loam, the fifth and sixth feet a hard and compact loam with much coarse grit, while the seventh to the tenth foot is sandy and micaceous. Underneath this through the twelfth foot the material is a bed of coarse water-worn grits.

While the soil is very similar to that of the Mylne orchard, the methods of treatment are quite different. In the Mylne orchard the mulch was but 3 or 4 inches deep, while in the Buelah grove it was 6 or 8 inches. No cultivation other than one a few days after irrigation was given the Mylne grove, while in the Buelah grove the soil was cultivated between irrigations. The Buelah grove was irrigated twenty-three days previous to this determination of moisture content.

The location of each of the points where soil samples were taken was opposite the upper, middle, and lower trenches of the Mylne grove. Observations on moisture content were not made preliminary to irrigation.

Percentages of water in soil of Beulah grove twenty-three days after irrigation.

Depth.	Upper.	Middle.	Lower.	Average.
Feet.				
1	6.25	3.70	6.98	5.64
2	7.18	3.95	8.52	6.55
3	8.05	7.15	10.70	8.63
4	10.46	6.56	9.04	8.69
5	8.46	6.89	8.87	8.07
6	12.48	11.53	9.74	11.25
7	10.95	10.18	11.64	10.90
8			11.58	
9			8.94	
10			4.57	
Averages.	9.12	7.14	9.05	8.53

The amount of water in the borings of the upper and lower parts of the furrows was nearly the same in each, but considerably lower in the middle, thus indicating accumulations at the ends, as already shown in other orchards.

THE CARSCADEN GROVE.

The Carscaden grove is located very near that of Mr. Mylne and has very nearly the same type of soil. There is a compact stratum at 1 foot depth, changing in the next 3 feet to a more easily penetrable loam. The fifth foot is a hardpan, the sixth a loam, and the seventh a hard, compact, and gritty loam. The method of cultivation is, however, different from other orchards in that a deep soil mulch of 8 inches is constantly maintained over the orchard. Irrigation water was applied to the orchard on July 5, and in from twenty-five to thirty-five days and also two months after irrigation samples of the soil were taken for moisture determinations from the several parts of the orchard. The results in percentages are given in the following table:

Percentages of water in soils of Carscaden grove thirty days after irrigation.

Depth.	West.	North.	East.	Middle.	General average.
Feet.					
1	7.96	5.62	6.47	6.47	6.63
2	9.39	5.85	9.23	8.33	8.20
3	10.52	7.13	10.11	10.38	9.53
4	7.91	8.39	8.34	9.59	8.56
5	3.92	12.24	11.56	10.24	9.74
6	8.50	10.96	7.46	....	8.97
7	9.07	11.48	15.02	....	11.89
8	....	9.02	11.56	....	10.29
9	....	9.13	11.37	....	10.25
10	....	13.00	8.14	....	10.57
11	....	11.07	4.36	....	7.72
12	....	8.72	2.82	....	5.77
	8.18	9.38	8.87	9.00	9.01

The general average of the entire 12 feet is 9.01 per cent, while that of the upper 5 feet in all of the columns is 8.48 per cent. The amount of water thus remaining in the soil thirty days after irrigation was very large, and was due to the excellent cultivation and mulching given the orchard, which enabled even the upper 4 feet to retain an average of a little more than 8 per cent. One month later (nearly two months after irrigation) the soils of the north and east corners were again examined, with the following results:

Percentages of water in soils after two months.

Depth.	West.		North.	
	July 27.	September.	July 31.	September.
Feet.				
1	7.96	3.11	5.62	2.75
2	9.39	6.34	5.85	2.32
3	10.52	8.85	7.13	4.78
4	7.91	7.93	8.39	5.28
5	3.92	4.18	12.24	9.63
6	8.50	5.18	10.96	10.75
7	9.07	8.37	11.48	10.74
Average.	8.18	6.28	8.81	6.61

These results show that in spite of the fact that good surface cultivation has been given to the soil and that the amount of water in July must have been materially reduced since the irrigation of twenty-five days before, the diminution continued through the succeeding months with an average reduction of about 2 per cent in the 7-foot columns. It is evident that an 8-inch mulch will not entirely prevent evaporation of water from the soil.

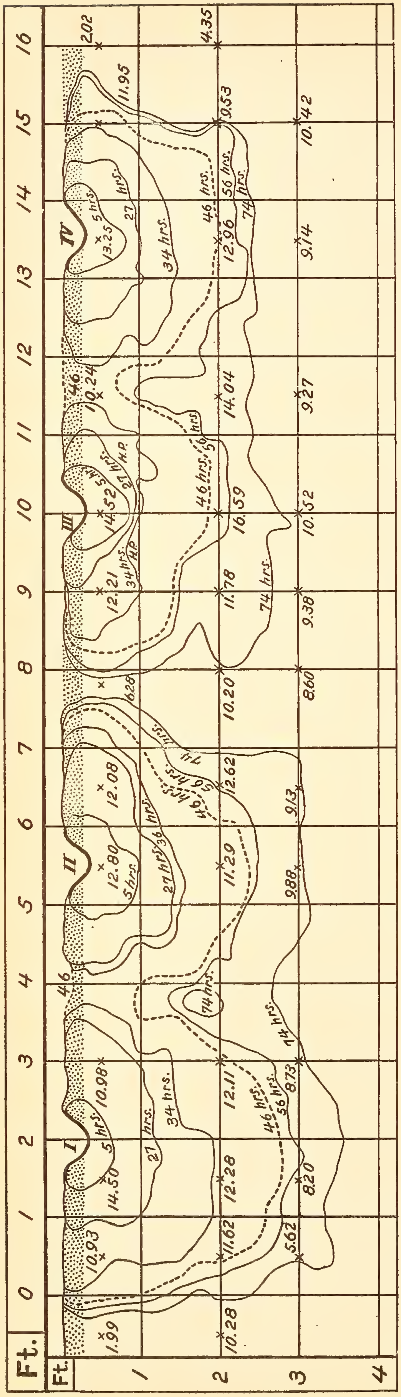

FIG. 17.—Outlines of percolation under four shallow furrows, Irving orchard.

THE IRVING ORCHARD.

The Irving orchard is located to the southward of the Mylne and Carscaden groves. Its soil is quite similar to that of the latter, being a heavy loam with more or less grit and inclined to become hard and compact when dry. But it does not seem to resist water penetration as does that of the Mylne orchard soil. The soil is well mulched to a depth of usually 6 to 8 inches.

The irrigation furrows are sometimes made with the usual shovel marker and given a depth of but a few inches in the loose soil mulch; or at other times a plow is used and the furrows are made of a greater depth, cutting into the hard subsoil.

Sometimes but three furrows are made between the tree rows, but at other times four or five are made. When five were used it was noticed that the entire surface of the soil between the trees was saturated in from twenty-four to thirty-six hours; with four furrows, most of the space, probably 85 per cent, was wet, while much less was wetted when only three furrows were made.

An opportunity presented itself for testing the movements of water under furrows made with the shovel and with the plow and Mr. Roadhouse took advantage of it. Trenches were dug across the three typical series of furrows, shallow four furrows, deep four furrows, and deep three furrows, and the conditions of irrigation were kept the same as far as the amount of water, etc., were concerned. The shovel made only shallow furrows within the 6-inch mulch, while the plow broke up the hard crust beneath the mulch with furrows 7 or 8 inches in depth.

Preliminary moisture determinations were made in the face of each of the trenches with the following results:

Percentages of water before irrigation.

Depth.	Shallow four furrows.	Deep four furrows.	Deep three furrows.
Feet.			
½	2.50	2.53	2.50
1	3.05	2.90	3.28
2	3.41	7.51	3.64
3	3.51	7.29	5.84
4	7.45	6.66	4.04
5	6.37	....	4.43
6	6.79	....	....

It was worthy of note that there was more water under the deep furrows than under the shallow in the depth of 4 feet, and that there was about the same amount under the shallow four furrows and the deep three furrows.

After the preliminary examinations had been made water was turned on and ran at the rate of 20 miner's inches during seventy hours. Observations were made on the sides of the trenches of the movements during successive periods and the results are outlined in the accompanying diagrams. Percolation under the four shallow furrows that were made with the shovel marker

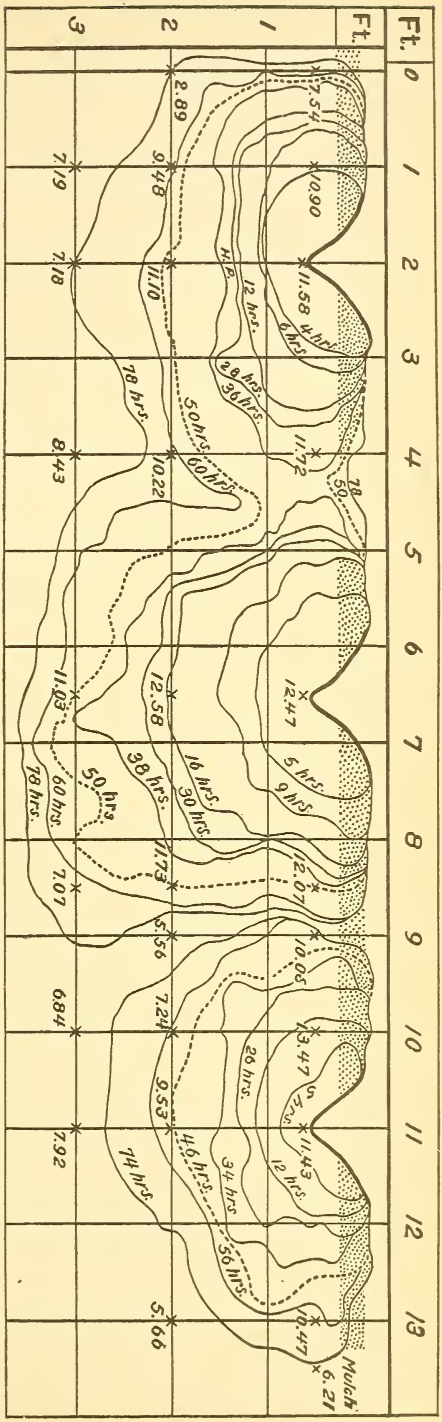

Fig. 18.— Outlines of percolation under three deep furrows, Irving orchard.

is shown in figure 17; that of the deep furrows made with the plow is shown on figures 18 and 19.

These diagrams show the usual great irregularity in the rate of movement of the water, in the outlines of percolation and wet areas during successive periods.

The following table presents a summary of depth beneath the bottoms of the furrows and the areas in the several curves:

Depths and areas of the wet soil beneath the furrows.

Four shallow furrows (shovel).			Four deep furrows (plow).			Three deep furrows (plow).		
Time.	Depth.	Area.	Time.	Depth.	Area.	Time.	Depth.	Area.
Hours.	*Inches.*	*Sq. ft.*	*Hours.*	*Inches.*	*Sq. ft.*	*Hours.*	*Inches.*	*Sq. ft.*
5	3–6	1.75	6–8	4–12	6.25	5	3–8	6.50
5–27	3–8	5.25	6–27	6–12	8.25	5–28	3–8	7.00
27–34	2–8	5.00	27–36	3–6	4.00	28–36	3–4	2.50
34–46[a]	6–9	8.00	36–48[a]	6–12	9.00	36–50[a]	3–6	6.50
46–74	6–12	13.50	48–76	6–9	16.75	50–78	3–11	11.00
74	2–3	33.50	76	3–4	44.25	78	4–5	33.50

[a] Water turned off.

The results are in favor of the deep-plowed furrows, both as to depth of penetration and area of absorption. The depth reached under the shovel-marked furrows was but 3 feet as a maximum, as shown in the diagram (fig. 16, p. 50), while that under the plowed furrows was 4.5 feet.

The area of absorption from the four shallow furrows was 33.5 square feet, which was equaled by the three deep furrows, while that of the four deep furrows was 44.25 square feet, or 32.1 per cent greater than that of the four shallow ones.

As the water percolated deeper and through a larger vertical section in the deep furrows, it would be supposed that a larger amount of water was caught from the irrigation flow, but much depends on the amount already in the soil when water was turned into the furrow, and also on the nature of the soil, whether readily permeable or not. The following table gives the results of the examination and shows the total percentages found in each 1-foot section twenty-four hours after irrigation ceased, and the amount probably absorbed from the irrigation flow:

Water in the vertical section.

	Depth.	Wet area.	Total.		Absorbed from irrigation flow.		
	Inches.	*Sq. ft.*	*Per cent.*	*Gallons.*	*Per cent.*	*Gallons.*	*Pounds.*
Four shallow furrows.....	3	33.50	11.08	46.6	6.08	25.6	214
Four deep furrows........	6	44.25	10.46	58.2	4.62	25.7	215
Three deep furrows.......	6	33.50	11.06	46.7	5.54	23.0	192

While the percentage of water was greater in the wet area below the four shallow furrows, the area under the four deep furrows was larger and hence the actual amount of water was somewhat greater; these deep furrows had, however, a greater percentage of water before irrigation than was found under the other, and this reduces the amount absorbed from irrigation to about the same number of gallons for each in the 1-foot section.

Under the three deep furrows there was the same wet area and the same percentage of water as under the four shallow furrows, but the greater amount of water previous to irrigation reduced the amount absorbed somewhat.

CONCLUSIONS.

The experience had in this first series of investigations on the disposal of water in furrow irrigation shows clearly that it is impractical to institute orchard observations of this character upon an area covered by more than a dozen tree rows at one time, because of the

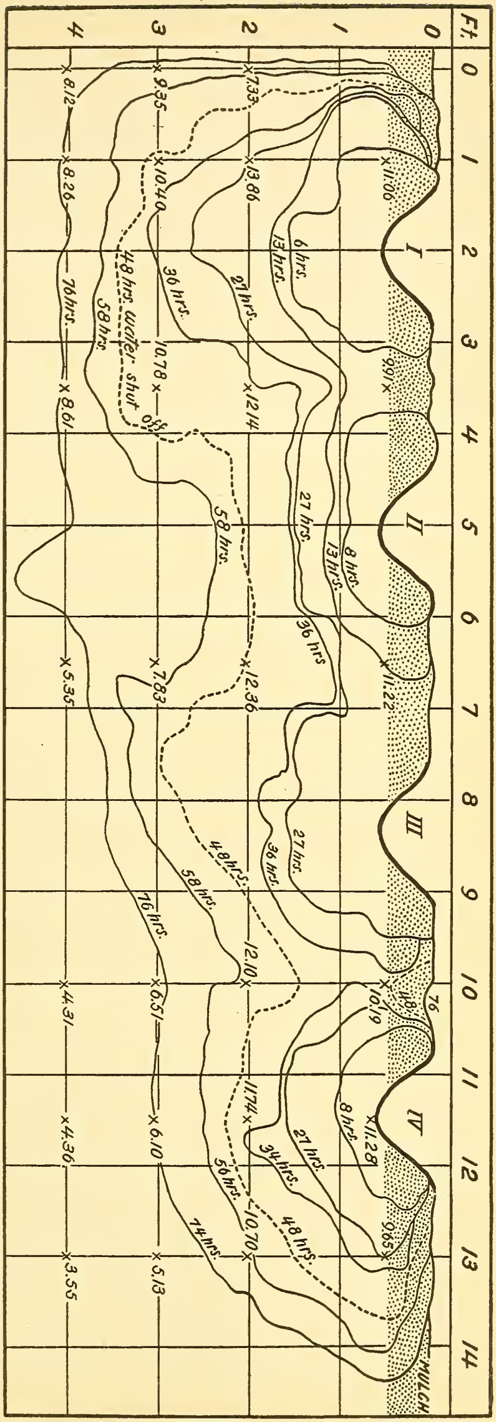

Fig. 19.—Outlines of percolation under four deep furrows, Irving orchard.

very short period (three days) occupied by each irrigation; and that before the water is turned into the furrows every preparation should be made for obtaining the desired data.

It was made evident also that trenches should be made across the furrows at short intervals from the head ditch to the lower end, which would show very correctly upon their faces the vertical and lateral movements of the percolating water at many points; troughs, of course, being placed to convey the flowing water across each trench. That these frequent trenches in orchard 58 would have added much of importance to the results obtained was not realized in time. The work thus far indicates that the following should be embraced among the observations to be made in the future:

Before irrigation.—Preliminary investigations as to the nature of the soil and moisture content to depths of 10 or more feet at many points.

During irrigation.—Observations on the movement and volume of water in the furrows; the direction, extent, and rapidity of percolation beneath the furrows; extent of wet surface from time to time.

Evaporation experiments on the wet soils in tanks, to be conducted simultaneously with irrigation, in order to ascertain the loss of water sustained by the continuously wetted soil from the initial application to the cutting off of the supply and then by the gradually drying soil to the time when it is mulched by cultivation.

After irrigation.—The final outline of water movement; determination of the amount of water held by the wet soil in the face of each trench; a series of borings at frequent intervals of space from the head ditch to the lower end of one or more furrows, to ascertain the depth of percolation along longitudinal lines.

The following is a brief summary of the results obtained in the orchards near Riverside as detailed above:

(1) The preliminary examination of the land of the orchard before irrigation showed that the upper 2 feet held only about 3.5 per cent of free water as the general average, while below this to the depth of 13 feet the average was 6.16 per cent. The roots of the trees were mostly confined to the upper 4 feet and in this depth there was an average of 4.68 per cent, an amount sufficient to maintain a good appearance in the trees but not to produce new growth; the application of irrigation water caused increased growth.

(2) The unobstructed movement of water in loam soils is downward, with great irregularity in rate of progress and in the amount of water retained at various depths. The water beneath the surface does not move from the furrows toward the trees for more than 2 feet, and at a depth below 2 feet the wet area is usually rapidly contracted to a cone shape. The soils in the tree rows, therefore, fail to receive any of the irrigation water, and the dry space increases

in width and extent downward; the tree roots, which usually are confined to the upper 3 feet, are thus only partially supplied with needed moisture.

(3) The relative proportion of dry soil to that wetted by irrigation across 16 furrows and four tree rows in the sandy loam soil, was as 2 to 3 in a depth of 5 feet. As seen in the profiles, the proportions are as follows, taking the dry soil as the unit: Surface foot, 1 to 3.4; second foot, 1 to 4.3; third foot, 1 to 2.3; fourth foot, 1 to 0.8; fifth foot, 1 to 0.4; and sixth foot, 1 to 0.1.

(4) The depth reached by the percolation of irrigation water depends on the nature of the soils and length of time of flow; in the unobstructed loose soil it was 26 feet near the head ditch, 4 feet in the middle, and about the same at 30 feet from the end, and many feet where the excess was received. In the compact, semi-impervious soil it reached a depth of 4 feet, while in the impervious hardpan soil the depth was but little more than 12 inches even after three days' application.

(5) The amount of water held by the soil when the downward movement ceased was always greatest in the upper 2 feet and diminished in percentage to the bottom. Thus in the general average of the long trench in orchard 58 we found under the nine furrows 9.95 per cent in the first foot, 11.19 in the second, 9.14 in the third, and 8.27 per cent in the fourth foot.

(6). The presence of an impervious hardpan near the surface causes sidewise seepage of the water, a greater wetting of the surface and consequent increased loss by evaporation and by accumulation and run-off at the lower end of the furrows.

(7) Shallow irrigation furrows do not give as good results as deep ones; they allow a large part of the water to rise by capillarity to the surface on either side and thence to escape into the air by evaporation, while deep furrows enable the soil to receive and retain nearly all of the water applied.

The furrows in orchard 58 had an average depth of 3 or 4 inches and from these the lateral seepage was so great as to wet about 85 per cent of the space between the tree rows. During the three days of irrigation in which these soils were being kept wet the rate of evaporation was very high. After this the soil gradually dried out and the loss diminished.

(8) On loose sandy loams water percolates with such rapidity near the head ditch that a great part is lost by passing far below the roots and possibly into sand and gravel strata, through which it flows away. Thus on orchard 58 the depth of percolation was 26 feet at a distance of 30 feet from the ditch.

It is extremely doubtful that water at a depth of more than 5 feet below the root systems will be of any benefit to the trees in times when needed, for the capillary rise is extremely slow, and especially so if the temperature of the soil be low. Observations made at the time of this investigation in July, when the air temperature was 102° F. in the shade and that of the surface soil 109° F., showed a difference of 28° at a depth of 1 foot and 42° at 13 feet. The following is the record.

Temperatures of a soil column in July.

Depth.	°F.	Depth.	°F.
Feet.		*Feet.*	
Surface	109.0	7	70.5
1	81.0	8	69.50
2	77.0	9	69.00
3	74.5	10	68.25
4	73.5	11	68.00
5	73.0	12	67.50
6	71.5	13	67.25

In another part of the same orchard in July when the temperature of the surface was 130° F. that at 13 feet was 69° F.

(9) In orchards with shallow mulches it was observed that the amount of water in the soil six weeks after irrigation was about the same as just previous to the application of water.

The rapidity of movement of water into a soil from the irrigation furrow and the rate at which it is carried into the lower soil strata is a matter of special importance to the trees whose roots must be in contact with it, and to the orchardist who wishes the soil to absorb all it possibly can and thus avoid waste by either run-off or evaporation into the air. Beyond this the orchardist, as a rule, seems to have no thought and takes for granted that the soil distributes the water properly to the roots. The fallacy of this reliance on the soil has been frequently proven by examination after irrigation, when it was shown that the water had penetrated to a depth of only a foot or less after a three days' flow in the furrows. Every orchardist should know his land thoroughly, with regard to its richness in elements of fertility, and especially with reference to its physical characteristics to depths of 6 or more feet, its relation to percolation, and its retention of irrigation water.

The percolation of water into the soil is influenced or controlled by a number of conditions:

By the air of the soil, which must give way before the advancing water—for otherwise it acts as a cushion and effectually prevents percolation of the water downward. This might happen in irrigation by flooding or by heavy rainfall, but in the furrow system the air escapes by lateral movement until the surface of the soil is saturated with seepage water from the furrows.

By coarse soil texture in which the water would meet with but little resistance on the part of the soil and gravity would cause it to sink rapidly downward.

By impervious or compact stratum, which would quickly arrest the downward movement of the water and cause its accumulation and probable loss by run-off.

By the root system of trees, which seems to facilitate percolation, but only along the lines of their extension and not through the soil.

By the kind of furrow made, whether wide or narrow, deep or shallow.

By cracks or crevices, holes or sand pockets, which of course afford a quick passage of the water deeply into the soil, which may mean a loss if the holes reach a bed of coarse sand or gravel.

Percolation is influenced by the time that water is allowed to remain in the furrow. The water should be made to reach the end of the furrow as soon as possible, and then the flow so regulated that the whole line may receive practically the same amount and to depths of 8 or 10 feet. If the movement is slow and the soil conditions favorable to percolation, then in the soil near the head ditch there is danger of loss by the percolation of the water far beyond the reach of the root systems. This was shown on the west side of orchard 58, where the water sank 26 feet near the head ditch, while at points down the furrows a depth of but a few feet was reached.

O

LIST OF PUBLICATIONS OF THE OFFICE OF EXPERIMENT STATIONS ON IRRIGATION—Continued.

Bul. 177. Evaporation Losses in Irrigation and Water Requirements of Crops. By Samuel Fortier. Pp. 64.

Bul. 179. Small Reservoirs in Wyoming, Montana, and South Dakota. By F. C. Herrmann. Pp. 100.

Bul. 181. Mechanical Tests of Pumping Plants in California. By J. N. Le Conte. Pp. 72.

Bul. 183. Mechanical Tests of Pumps and Pumping Plants Used for Irrigation and Drainage in Louisiana in 1905 and 1906. By W. B. Gregory. Pp. 72.

Bul. 188. Irrigation in the Yakima Valley, Washington. By S. O. Jayne. Pp. 89.

Bul. 190. Irrigation in Northern Italy—Part II. By Elwood Mead. Pp. 86.

Bul. 191. Tests of Internal Combustion Engines on Alcohol Fuel. By C. E. Lucke and S. M. Woodward. Pp. 89.

Bul. 201. Cost of Pumping from Wells for the Irrigation of Rice in Louisiana and Arkansas. By W. B. Gregory. Pp. 39.

FARMERS' BULLETINS.

Bul. 116. Irrigation in Fruit Growing. By E. J. Wickson. Pp. 48.

Bul. 138. Irrigation in Field and Garden. By E. J. Wickson. Pp. 40.

Bul. 158. How to Build Small Irrigation Ditches. By C. T. Johnston and J. D. Stannard. Pp. 28.

Bul. 263. Practical Information for Beginners in Irrigation. By Samuel Fortier. Pp. 40.

Bul. 277. Use of Alcohol and Gasoline in Farm Engines. By C. E. Lucke and S. M. Woodward. Pp. 40.

CIRCULARS.

*Circ. 48. What the Department of Agriculture is Doing for Irrigation. By Elwood Mead. Pp. 4.

*Circ. 58. Irrigation in the Valley of Lost River, Idaho. By Albert Eugene Wright. Pp. 24.

*Circ. 59. Progress Report of Cooperative Irrigation Investigations in California. By S. Fortier. Pp. 23.

*Circ. 63. Work of the Office of Experiment Stations in Irrigation and Drainage. Pp. 31.

Circ. 65. Irrigation from Upper Snake River, Idaho. By H. G. Raschbacher. Pp. 16.

Circ. 67. Investigations of Irrigation Practice in Oregon. By A. P. Stover. Pp. 30.

SEPARATES.

*Rise and Future of Irrigation in the United States. By Elwood Mead, Expert in Charge of Irrigation Investigations, Office of Experiment Stations. Pp. 591–612. (Reprint from Yearbook, 1899.)

*Some Typical Reservoirs in the Rocky Mountain States. By Elwood Mead, Chief of Irrigation Investigations, Office of Experiment Stations. Pp. 415–430. (Reprint from Yearbook, 1901.)

*Preparing Land for Irrigation. By R. P. Teele. Pp. 239–250. (Reprint from Yearbook, 1903.)

*Potato Culture near Greeley, Colo. By J. Max Clark. Pp. 311–322. (Reprint from Yearbook, 1904.)

The Relation of Irrigation to Dry Farming. By Elwood Mead, Chief of Irrigation and Drainage Investigations, Office of Experiment Stations. Pp. 423–438. (Reprint from Yearbook, 1905.)

The Use of Small Water Supplies for Irrigation. By Samuel Fortier, Chief of Irrigation Investigations, Office of Experiment Stations. Pp. 409–424. (Reprint from Yearbook, 1907.)

*The Scope and Purpose of the Irrigation Investigations of the Office of Experiment Stations. By Elwood Mead, Irrigation Expert in Charge. Pp. 317–327. (Reprint from Annual Report of Office of Experiment Stations for 1901.)

Review of Irrigation Investigations for 1902. By Elwood Mead, Chief of Irrigation Investigations, Office of Experiment Stations. Pp. 359–385. (Reprint from Annual Report of Office of Experiment Stations for 1902.)

Review of Irrigation Investigations for 1903. By Elwood Mead, Chief of Irrigation Investigations, Office of Experiment Stations. Pp. 469–502. (Reprint from Annual Report of Office of Experiment Stations for 1903.)

Report of Irrigation and Drainage Investigations, 1904. By Elwood Mead, Chief. Pp. 425–472. (Reprint from Annual Report of Office of Experiment Stations for 1904.)